A Novel Routing Protocol Providing Good Transmission Reliability in Underwater Sensor Networks

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Abstract

As the network communications technology developing, a new type of networks has appeared in the daily life which is named underwater sensor networks (UWSNs). UWSNs are a class of emerging networks that experience variable and high propagation delays and limited available bandwidth. There are comprehensive applications in this area such as oceanographic data collection, pollution monitoring, offshore exploration, assisted navigation and so on. Due to the different environment under the ocean, routing protocols in UWSNs should be re-designed to fit for the surroundings. In particular, routing protocols in UWSNs should ensure the reliability of message transmission, not just decrease the delay. In this paper, we propose a novel routing protocol named Location-Aware Routing Protocol (LARP) for UWSNs, where the location information of nodes is used to help the transmission of the message. Simulation results show that the proposed LARP outperforms the existing routing protocols in terms of packet delivery ratio and normalized routing overhead. We expect LARP to be of greater value than other existing solutions in underwater environment.

Keywords: Underwater sensor networks (UWSNs), Location-aware, Anchor node, Reliability.

1 Introduction

Underwater sensor networks (UWSNs) are a class of emerging networks that experience variable and high propagation delays and limited available bandwidth. Compared with ground-based networks, UWSNs has more attractiveness due to its distinctive characteristics and the comprehensive applications. UWSNs are very interesting in the ocean exploration applications and very important in military applications, such as oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications [1]. In addition, Multiple unmanned underwater vehicles (UUVs) and autonomous underwater vehicles (AUVs) equipped with underwater sensors will also find application in exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions [10].

UWSNs have great potential and contain enormous values in economic and social field [2][24]. Sensors and vehicles under water manage and organize by themselves in an autonomous network which can adapt to the characteristics of the ocean environment in order to carry out a great variety of explore and research missions [13]. Because of the different environment under the ocean, the routing protocol should be re-designed to fit for the surroundings. However, the different environments under the ocean and such distinct features compared with the ground-based networks pose a number of technical challenges in designing the routing protocol [3]. In this paper, we propose a novel routing protocol named Location-Aware Routing Protocol (LARP) for UWSNs, where the location information of nodes are used to help the message transmission. Resort to a range-finding technique called received signal strength indicator (RSSI) [9], a node can easily obtain its location information [5]. Simulation results show that the presented LARP outperforms the existing routing protocols in terms of packet delivery ratio and normalized routing overhead.

The rest of this paper is organized as follows. In the following section, related works on routing protocols in UWSNs are briefly discussed. A Novel Location-Aware Routing Protocol for UWSNs is described in detail in Section 3. Simulations and results are presented in Section 4. Finally, the conclusions of this paper are covered in Section 5.

2 Related Works

Compared with ground-based networks, UWSNs has the following key properties: (1) acoustic wireless communication, (2) variable and high propagation Delays,

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(3) limited available bandwidth, (4) severely impaired channel, (5) high bit error rates and limited battery power, (6) fouling and corrosion. Some researchers have made a lot of effort in designing new protocols in this area [16-19]. In general, the routing protocols in UWSNs are classified into three categories: proactive, reactive and geographical routing protocols.

2.1 Proactive Routing Protocols

The proactive routing protocols attempt to minimize the message latency induced by route discovery, by maintaining up-to-date routing information at all times from each node to every other node. This is obtained by broadcasting control packets that contain routing table information. These protocols provoke a large signaling overhead to establish routes for the first time. In addition, when the network topology is modified due to node mobility or node failures, the updated topology information has to be propagated to all the nodes in the network. The representative of this category is destination-sequenced distance-vector (DSDV) [4] protocol.

DSDV is a proactive hop-by-hop distance vector routing protocol. Every host maintains a routing table for all the possible destinations and the number of hops to each destination. Meanwhile, each host broadcasts routing updates periodically in order to achieve the latest and the most accurate routing table [4].

2.2 Reactive Routing Protocols

In reactive routing protocols, a node initiates a route discovery process only when a route to a destination is required. Once a route has been established, it is maintained by a route maintenance procedure until it is no longer desired. These protocols are more suitable for dynamic environments but incur a higher latency and still require source-initiated flooding of control packets to establish paths. Note that the latency caused by reactive protocols in the establishment of paths may be even amplified underwater by the slow propagation of acoustic signals. Furthermore, links are likely to be asymmetric, due to bottom characteristics and variability in sound speed channel. The representative of this category is ad hoc on-demand distance vector routing (AODV) [6] protocol.

AODV is an improvement on DSDV because it minimizes the number of the required broadcasts by creating routes on demand basis [6]. It carries out the route discovery by using on-demand mechanism and maintains from DSR [14].

2.3 Geographic Routing Protocols

These protocols establish source–destination path by the localization information. Each node selects its next hop based on the position of its neighbors and of the destination node. In fact, fine-grained localization usually requires strict synchronization among nodes, which is difficult to achieve underwater due to the variable propagation delay. Virtual circuit routing techniques can be considered in UWSNs. In these techniques, paths are established a priori between each source and sink, and each packet follows the same path. Localization schemes are the most important issues in geographic routing protocols [7]. The representative of this category is area localization scheme (ALS) [8] for UWSNs.

In very large and dense wireless sensor networks, a coarse estimate of the sensors' locations may suffice for most applications. ALS [8] tries to estimate the position of every sensor within a certain area rather than its exact location. The granularity of the areas estimated for each node can be easily adjusted by varying system parameters. All the complex calculations are handled by the powerful sinks instead of the sensors. This reduces the energy consumed by the sensors and helps extend the lifetime of the network.

We evaluate the three kinds of routing protocols such as proactive routing protocols, reactive routing protocols and geographic routing protocols, in terms of various characteristics including important performance metrics. Flexibility, route acquisition, resource usage, flood for route recovery, latency, overhead, routing table, and effectiveness are studied in the comparative analysis. Table 1 summarizes the comparison results. From Table 1 and our comparative

Table 1 Comparison of the Three Different Kinds of Routing Protocols

	Flexibility	Route acquisition	Resource usage	Flood for route discovery	Latency	Overhead	Routing table	Effectiveness
Proactive routing protocols	Bad	Computed a priori	High	No	Short	High	Yes	Bad
Reactive routing protocols	Normal	On-demand	Normal	Yes	Long	Normal	Yes	Bad
Geographic routing protocols	Good	Computed a priori	Low	No	Normal	Low	No	Good

analysis, some conclusive comments can be inferred: The geographic routing protocols are the most suitable for underwater communication.

3 A Novel Location-Aware Routing Protocol for UWSNs

In this section, LARP is described in detail. LARP belongs to geographical routing protocols, which can provide good reliability and validity of message transmission. Note that the location information of nodes is used to help the transmission of the message in LARP.

Suppose that two kinds of nodes exist in the network. One is anchor node, the other is general node. We utilize anchor nodes to estimate the location information of general nodes. We determine the best next hop to relay the message by location information [22-23]. In our protocol, anchor nodes equipped with GPS traverse the sensor network and broadcast beacon packets, which contain the location coordinates. RSSI measurements of the received beacon packets are used for ranging purposes. General nodes estimate the location information by cooperating with at least three anchor nodes. Every node stores its own location information. When an anchor node is situated in the transmission range of a certain general node, the information of this general node can be stored in this anchor node. In addition, we pre-determine some properties about the anchor nodes to preferably route data from source to destination: (i) All the anchor nodes have enough energy and capability of storing; (ii) Radio transmission range of the anchor node is large enough to cover the whole scale of the network; (iii) Location of the anchor node can be exactly obtained by GPS or other assistant methods [20]; (iv) All the anchor nodes can move randomly around the network.

The proposed routing protocol has two steps. At the beginning of routing, the location information of destination node should be obtained by the source first. Suppose that there is a message transmitted from the source (S) to the destination (D). If there is an anchor node in the transmission range of node S, S can request the anchor node to find the destination's location. Otherwise, node S will wait until an anchor node appears in its transmission range. After this anchor node broadcasts the ID of the destination node, all the other anchor nodes will check their lists to find the destination node. If one anchor node finds the destination node, the source can obtain the information about it.

After node S getting the information of the destination D, the second step is determining the next hop for this transmission. In the beginning, node S broadcasts "destination location" request. As shown in Figure 1. If node D is in the transmission range of S, then D replies to S before S directly transmitting the message to D. Otherwise, no node replies to S, and node S broadcasts the "moving direction" request. All the information of nodes in the transmission range of S is collected by S through directly communicating with these nodes. As shown in Figure 2, node A's moving direction is same as the message's transmission direction, so node A replies to S and the message is delivered to A immediately. That is to say, A becomes the best next hop. Note that the moving direction information can be easily calculated by the location information at different times. If two nodes have the same moving direction as the message's transmission direction, then the node with higher speed can only become the next hop. If all the moving directions of nodes in the transmission range of S are different from the message's transmission direction, then no node replies to S [21]. Therefore, node S will wait.

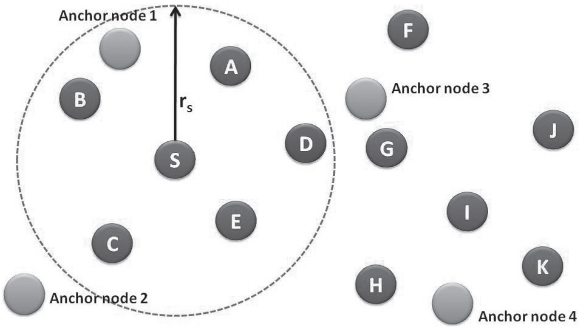

Figure 1 Node S Broadcasts "Destination Location" Request

Finally, the best next hop is decided. The message is delivered and stored in this intermediate node, which continues to determine the next hop until the message successfully arriving at the destination node.

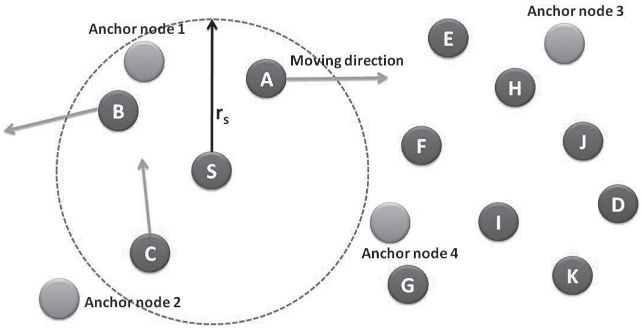

Figure 2 Node A Replies to Node S

4 Simulations and Results

4.1 Simulation Environment

We implemented LARP by using the ns-2 simulator. The implementation of our proposed routing protocol is based on the Monarch [11] extensions to ns-2. The IEEE

802.11 [12] Medium Access Control (MAC) protocol is implemented in Monarch. We model 50 nodes (including 10% anchor nodes) in a square area 1,000 m × 1,000 m during the simulation time 1,000 s. Each node picks a random spot in the square and moves with a speed uniformly distributed between 0 ~ 5 m/s. The radio transmission range is assumed to be 250 meters and a two ray ground propagation channel is assumed. Most other parameters use ns-2 defaults. The parameters for the simulation are given in Table 2 in detail. Nodes are generated randomly in an area and move according to the well-known Random waypoint mobility model.

Table 2 Parameters Used in the Simulation

Parameter	Value
Number of node	50
Mobility model	Random way point
Mac	IEEE 802.11 DCF
Traffic source	CBR for UDP-based traffic
Node speed	0 ~ 5 m/s
Propagation model	Two-ray ground reflection
Simulation time	1,000 seconds
Data transmission rate	2 Mbps
Radio transmission range	250 meters
Pause time	0, 20, 50, 100, 300, 600, 900s
Packet outgoing rate	1, 2, 4, 8, 16 packets/sec
Number of sessions	2, 6, 10, 14, 18

Three performance metrics of packet delivery ratio, normalized routing overhead and packet delivery end-to-end delay are compared. First of all, we are interested in the packet delivery ratio, i.e. how many packets are delivered to the destination. The definition of packet delivery ratio is given in Equation (1).

$$\begin{aligned}&\textit{Packet delivery ratio}\\&=\frac{\textit{Number of delivered packets}}{\textit{Number of generated packets}}\end{aligned}\qquad(1)$$

Second, we study the normalized routing overhead of the whole network. This indicates the system resource utilization and consumption. The equation of normalized routing overhead is described in Equation (2).

$$\begin{aligned}&\textit{Normalized routing overhead}\\&=\frac{\textit{Number of routing packet transmission}}{\textit{Number of data packet transmission}}\end{aligned}\qquad(2)$$

Finally, it is of interest to consider the average end-to-end delay of packet delivery to find out how much time it takes for a message to be delivered. The calculation of average end-to-end delay is shown in Equation (3).

$$\begin{aligned}&\textit{Average end-to-end delay}\\&=\textit{average value of (delivered packet's timestamp}\\&\quad-\textit{generated packet's timestamp)}\end{aligned}\qquad(3)$$

We ran simulations for each scenario. For measuring the three performance metrics, two simulation factors of the pause time and the packet outgoing rate (transmission rate) are varied in a meaningful range (i.e., the pause time is from 0 to 900 s, the packet outgoing rate is from 1 to 16 packets/sec, and the number of sessions is from 2 to 18 are applied). While one simulation factor is varied during a simulation, the others are fixed as follows: the pause time is 100 s, the packet outgoing rate is 4 packets/sec, and the number of sessions is 6.

4.2 Results and Discussion

We present a comparative simulation analysis of LARP with DSDV, AODV and ALS.

4.2.1 Packet Delivery Ratio

The first interesting aspect that we analyze is the packet delivery ratio, a characterizing aspect of a protocol for underwater sensor networks. We investigate the packet delivery ratio of the protocols in different scenarios, which are shown in Figures 3, 4 and 5. It is easy to see that the pause time, transmission rate, and number of sessions impact the packet delivery ratio.

As shown in Figure 3, the packet delivery ratio gradually increases as the pause time increases. This is intuitive, since a larger pause time means that nodes are more close to static and the networks are more stable. In particular, the packet delivery ratio of DSDV, AODV and ALS has a transient decrease when the pause time is 100 s.

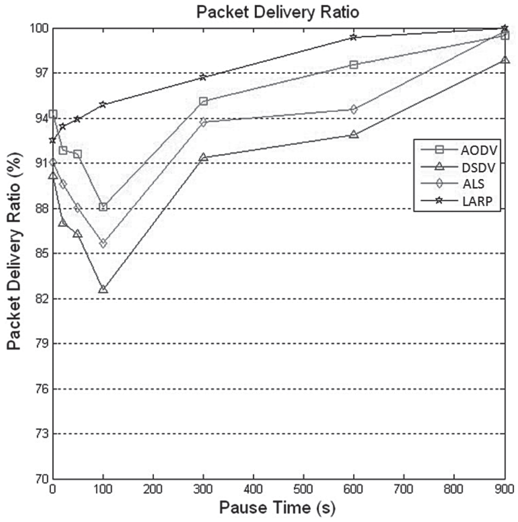

Figure 3 Packet Delivery Ratio versus Pause Time

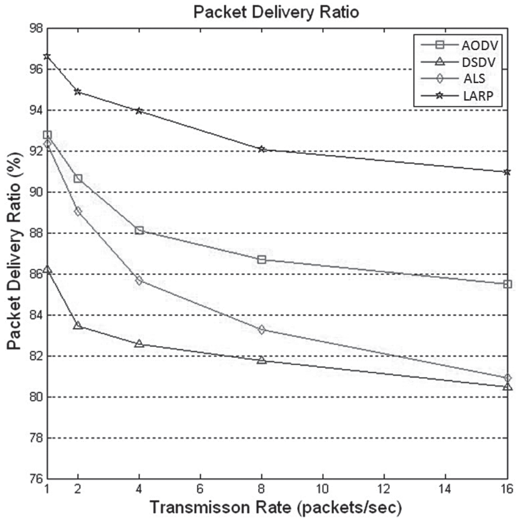

Figure 4 Packet Delivery Ratio versus Transmission Rate

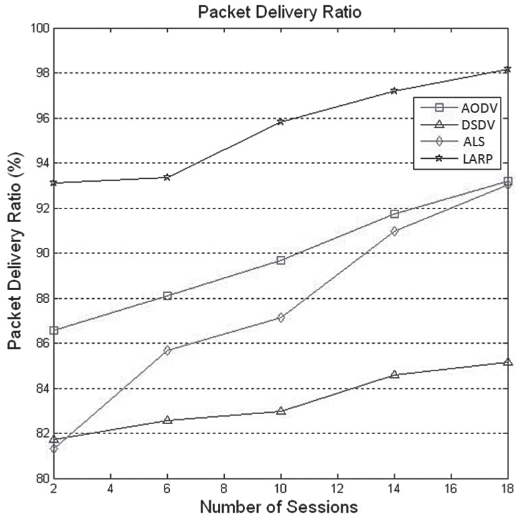

Figure 5 Packet Delivery Ratio versus Number of Sessions

This pause time is not enough to establish a stable routing path and breaks down the mobility. It leads to the unstable path between each other. Hence, the curves of DSDV, AODV and ALS sharply drop back. It is worth noting that the packet delivery ratio of LARP persistently increases as the pause time rises up. Compared with the other three routing protocols, the packet delivery ratio of LARP is the best. It always maintains a high packet delivery ratio under different pause time. Figure 4 describes the change of packet delivery ratio when the packet outgoing rate increases. Seen from Figure 4, the packet delivery ratio reduces as the transmission rate rises up. Note that LARP has the highest packet delivery ratio under various packet transmission rates. As depicted in Figure 5, the packet delivery ratio gradually increases as the number of sessions increases. The number of sessions defines the maximum number of connections between nodes. Similar to Figure 3 and Figure 4, LARP has the highest packet delivery ratio in each metric.

4.2.2 Normalized Routing Overhead

Another critical aspect we investigated is the normalized routing overhead. Figures 6, 7 and 8 show the impact of pause time, transmission rate and number of sessions on the normalized routing overhead. As we know, normalized routing overhead indicates the system resource utilization and consumption. It is an important criterion to evaluate the performance of routing protocols. In these simulations, LARP has lower routing overhead compared with other routing protocols and the curve of LARP looks like more stable than that of other routing protocols.

Figure 6 shows that the routing overhead decreases as the pause time increases. Note that the change of the normalized routing overhead in LARP is small. It indicates that the performance of LARP is stable. When the pause

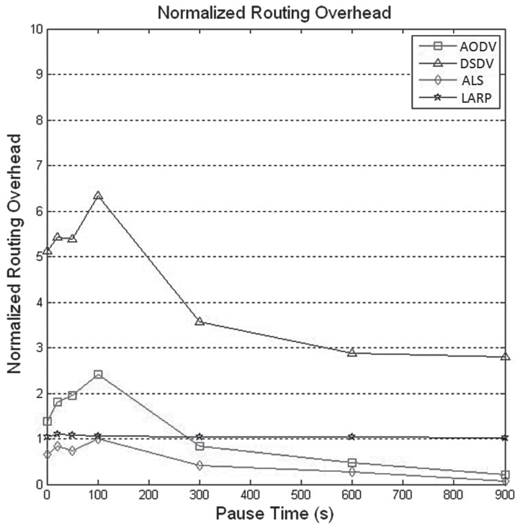

Figure 6 Normalized Routing Overhead versus Pause Time

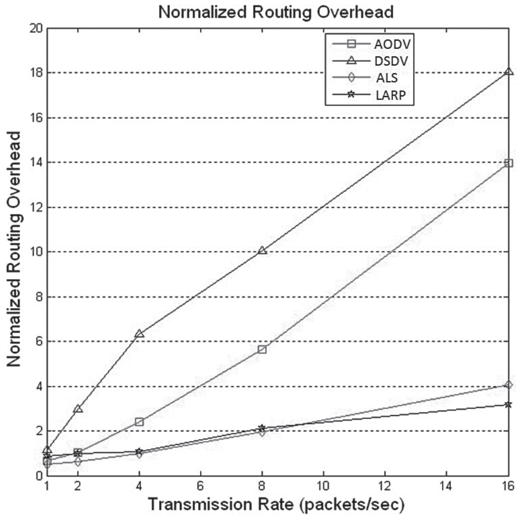

Figure 7 Normalized Routing Overhead versus Transmission Rate

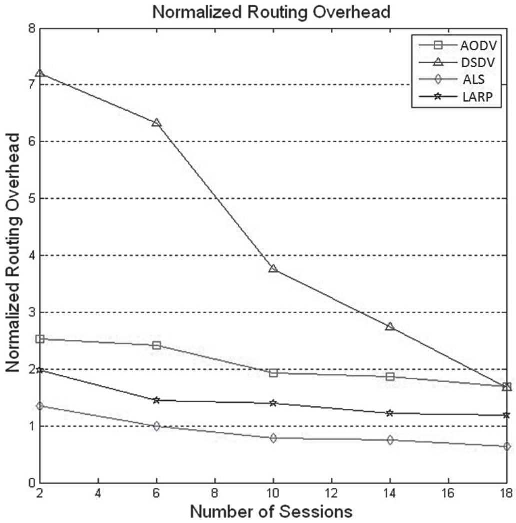

Figure 8 Normalized Routing Overhead versus Number of Sessions

time is more than 300 s, the routing overhead of LARP is a little higher than AODV and ALS. That's because the simulation environment trends to be static and the mobility of node declines. Figure 7 presents that the routing overhead increases as the transmission rate increases. Observed from the shape of the LARP's curve, the routing overhead of LARP always maintains at a low level in most cases. Similarly, Figure 8 depicts that LARP has a low routing overhead under different number of sessions.

4.2.3 Average End-to-End Delay

It is still of interest to consider the average end-to-end delay to find out how much time it makes a message to be delivered. Figures 9, 10 and 11 show the impact of pause time, transmission rate and number of sessions on the average end-to-end delay.

Viewed from Figures 9, 10 and 11, the average end-to-end delay of LARP is longer than other three routing protocols in most cases. Note that, in LARP, nodes are required enough time to obtain the information of location. It dooms that the nodes need to usually gather and update the information in a certain time interval. The feature of the average end-to-end delay in LARP determines that LARP can be only implemented in the environment which focuses on the reliability and validity of message transmission rather than delivery delay.

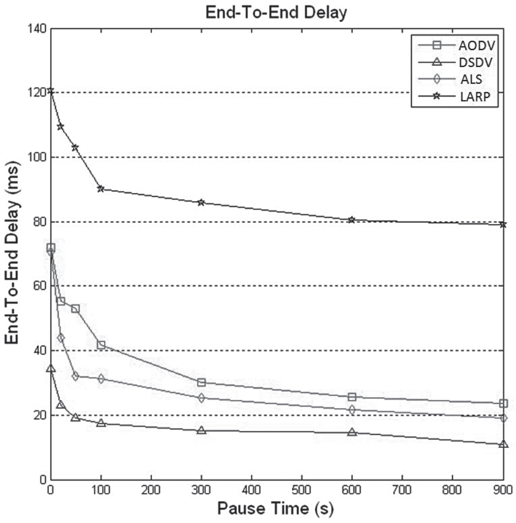

Figure 9 End-to-End Delay versus Pause Time

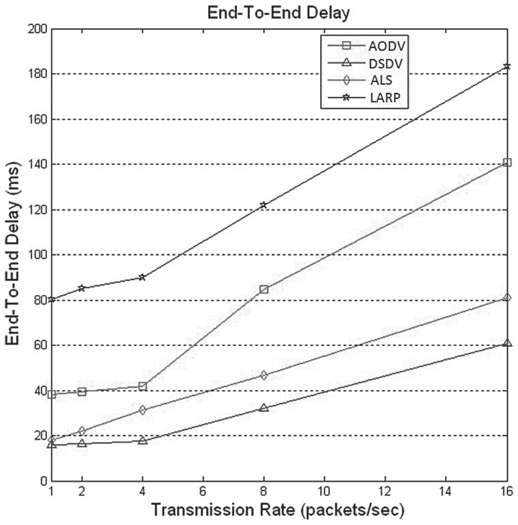

Figure 10 End-to-End Delay versus Transmission Rate

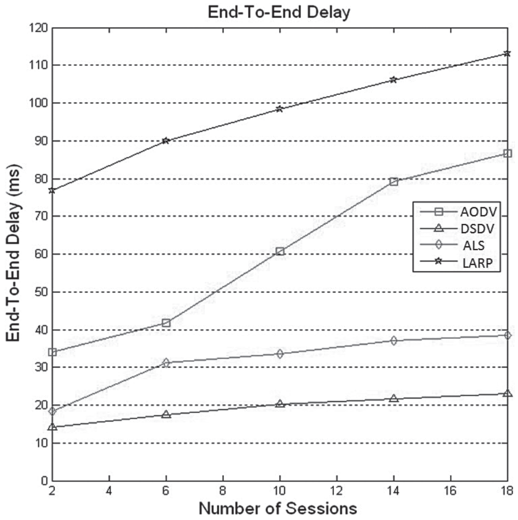

Figure 11 End-to-End Delay versus Number of Sessions

5 Conclusions

In this paper, we have proposed a routing protocol named LARP for UWSNs, which utilizes the location information of nodes to transmit a message. Resort to a range-finding technique RSSI, a node can easily obtain its location information. The simulation experiments have shown that LARP is able to ensure the reliability of message transmission. It is worth noting that LARP can be implemented in the environment which focuses on the reliability and validity of message transmission rather than delivery delay.

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