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Evaluation of Multi-hop Ad-hoc Routing Protocols in Wireless Seismic Data Acquisition

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Abstract: Due to impediments associated with cable-based seismic survey, Wireless Seismic Data Acquisition (WSDA) has recently gained much attention from contractors, exploration companies, and researchers to layout enabling wireless technology and architecture for Wireless Geophone Networks (WGN) in seismic explorations. A potential approach is to employ multi-hop wireless ad-hoc communication. In this study, we propose a multi-hop WGN architecture consisting of several subnetworks to realize the expected network performance. We investigate the performance of proactive and reactive routing protocols to examine the optimal number of geophones that could be effectively supported within a subnetwork. The performance metrics used are packet delivery ratio (PDR) and average end-to-end delay.

Keywords: Wireless Geophone Network (WGN), Wireless Gateway (GW), Central Control Unit (CCU), Wireless Seismic Data Acquisition (WSDA)

1 Introduction

Seismic survey is a method of obtaining an image of the earth's sub-surface structure in order to determine optimal places to drill for oil and gas. In land survey, an energy source generates variable frequency waves (referred to as sweep or shot) that propagates down the earth's surface. These waves are reflected and refracted as they hit various subsurface layers, which are recorded by devices at the surface called geophones and then sent down to the Central Control Unit (CCU) for further processing. The source is then moved to the next shot point and the process is repeated. Depending on the coverage area, the survey can last for several weeks. A measured geophone response sampled at 0.5 ms and digitized with 24 bit resolution will result in a data rate of 48 kbit/s. WGNs are often large-scale networks with tens of thousands of geophones deployed along receiver lines, covering several squares of kilometres of the survey area. For real-time WSDA systems, defining a scalable network architecture and employing a suitable wireless technology is of essential importance. Infrastructure based architectures for WGNs have been proposed in many literatures, [RSA+19] etc., whereby group of geophones transmit their sensed data to a wireless gateway (GW), and from the gateway down to the CCU in single-hop. However, this increases the number of GWs to be deployed in the survey. Higher data rate, higher communication coverage, and regard for imposed cost are some of the key factors to consider when selecting wireless technology for WGNs.

Network Architecture: Our proposal is to enable multi-hop ad-hoc communication in the WGN architecture proposed in [MKT21], to reduce the number of GWs to be deployed, while keeping the WGNs performance intact. Therefore, a flat-based network architecture in which the survey area is divided into subnetworks is employed (Figure 1). Each subnetwork consists of certain number of geophones that relay their seismic data via neighbouring geophones to a GW node over multi-hop wireless network. The GW then forwards the aggregated data to the CCU. The size of the subnetwork determines the optimal number of hops supported satisfying the WGN requirements, with 100% PDR and the upper limit of the delay for real-time acquisition systems. To limit the effect of adjacent and co-channel interference, neighbouring GWs are expected to use non-overlapping channels in such a way that no adjacent subnetwork uses the same channel.

Traffic Demand in a Subnetwork: The common orthogonal geometry where receiver and source lines are placed perpendicular to each other is employed [CGP00]. Geophones are placed on four parallel receiver lines, separated by a distance of 200 m and an inter-geophone distance of 25 m as defined in a typical survey [RSA^{+}19]. The traffic from each geophone is generated according to the geophone recording period acquisition technique in [MKT21], at a rate of 48 kbit/s which is transmitted to the GW node. Depending on the number of hops, a forwarding geophone will transmit twice the rate or more, as shown in Figure 1 (logical view). Although the data generated per geophone is quite small, the aggregate data generated in a subnetwork could be significantly large. If the subnetwork size has been selected with up to 200 nodes maximum, around 9.6 Mbit/s of the network capacity will be required with per node data rate of 48 kbit/s, assuming all nodes can reach the GW in a single hop. However, this value increases with more number of hops in the network. Moreover, when various protocol headers are taken into consideration the available bit rate is less than the nominal data rate.

Wireless Technologies: Considering the large-scale geophone deployment and higher data rate requirements, wireless communication technologies/protocols used in conventional Wireless Sensor Networks (WSN) such as, IEEE 802.15.4 or LoRa are not suitable for WGNs. Longer range random access technologies like IEEE 802.11af and IEEE 802.11ah are more suitable as they can cover more geophones and can provide higher data rates.

The main goal of this work is to evaluate a suitable routing protocol to enable multi-hop ad-hoc communication in a WGN subnetwork with acceptable network performance. Ad-hoc in this work refers to infrastructure-less communication. Many routing protocols for wireless ad-hoc networks have been discussed and classified based on the underlying network structure (i.e. flat, tree, mesh, and hierarchical based) in literature [PNV13].

The ad-hoc routing protocols are categorized as pro-active, reactive, and hybrid [PNV13]. In proactive protocols route to destinations are established and maintained by periodically distributing routing information in the network. In reactive protocols, route discovery is initiated only on demand from source nodes. Two prominent proactive protocols i.e., Optimised Link State Routing “OLSR” (mostly used in mobile ad-hoc networks) and IPv6 Routing Protocol for Low-Power and Lossy Networks “RPL” (commonly used in WSNs), and a widely used reactive protocol i.e., Ad-hoc On-demand Distance Vector “AODV” are investigated in this study. IEEE 802.11g, which has same random access behavior of CSMA/CA like in IEEE 802.11af, IEEE 802.11ad, is used as an example MAC protocol to evaluate the multi-hop routing protocols.

OLSR is based on link-state algorithm, that uses the concept of multipoint relays (MPR) to

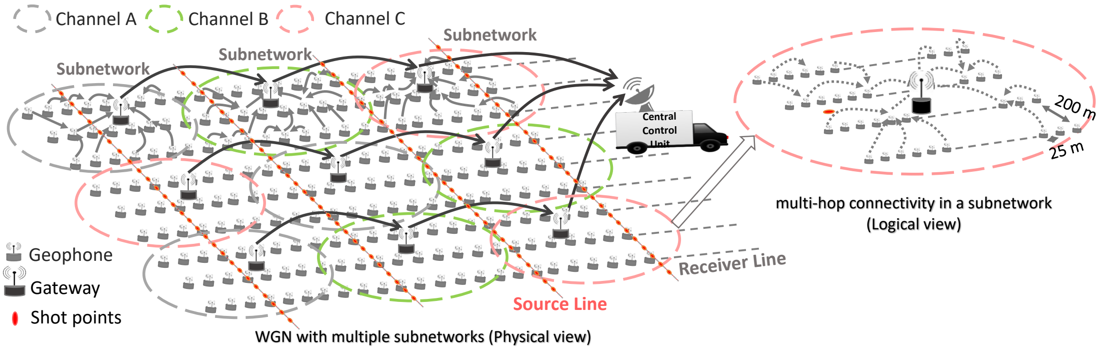

Figure 1: Architecture for Wireless Geophone Networks

optimize the number of control messages flooded in the network. RPL is an IPv6 distance vector protocol that employs the concept of Destination Oriented Directed Acyclic Graph (DODAG) to establish network topology, with all links oriented towards the sink or DODAG root. It uses an objective function to construct routes, which define how routing metrics and other constraints are taken into account when building the network topology[WTB+12]. AODV is a distance vector protocol based on the bellman-ford algorithm in which route discovery is initiated on demand by a transmitting node. Using OMNeT++ simulation tool, we evaluate the performance of these protocols considering WGN's traffic pattern, network size and structure to analyze the size of a subnetwork.

2 Results Analysis

One subnetwork with various network size settings is configured in OMNeT++ simulator as shown in Figure 1. Each geophone accumulates the data during the interval of 250 ms and send the accumulated data periodically till the end of geophone recording period of 5 s, for a single shot. The payload size of a single packet is configured as 1500 B (= 48 kbit/s at 250 ms). IEEE802.11g is used with ad-hoc mode of operation supporting both 11 Mbit/s and 54 Mbit/s data rates. The latter is used to investigate the routing protocol performance for the maximum achievable data rate in 802.11g, as 11 Mbit/s might not be enough to cater for our application data rates over several hops.

Figure 2 shows WGN requirement of the PDR of 100% can be achieved only up to 20 nodes irrespective of the type of routing protocol used to enable multi-hop communication in a sub network, when using 11 Mbit/s. The offered load approaches the maximum capacity the network can handle, thereby leading to severe packet loss at the MAC layer due to retransmission failures or queue overflow. In addition to the offered load, routing overhead resulting from periodic exchange of hello message and topology control messages further occupies the network capacity. In general, higher number of routing overhead is involved in proactive compared to reactive routing. Here, AODV shows a slight improvement in PDR beyond 20 nodes with 11 Mbit/s. Some cases, RPL shows better PDR, compared to OLSR as it uses the trickle timer algorithm to dynamically adjust the rate of sending control packets.

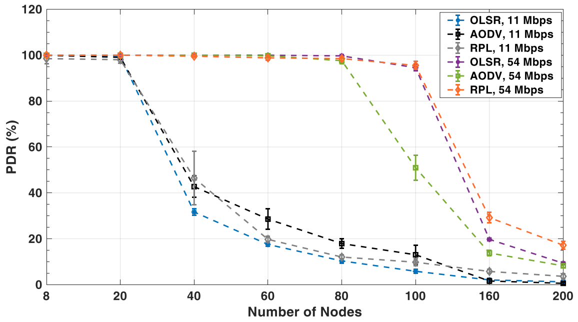

Figure 2: Packet delivery ratio

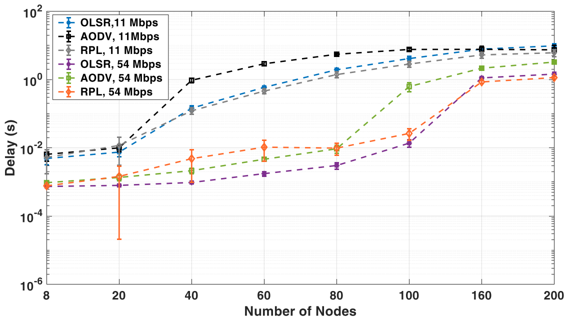

Figure 3: Average end-to-end delay

The PDR of RPL and OLSR outperform AODV when using 54 Mbit/s. The PDR for all protocols closely follows till the network size (N) of 80 where the network capacity can bear the offered load and the routing overhead with mulit-hop communication. At N = 100, the PDR for AODV protocol significantly drops to almost 50%. This is caused by the specific traffic model of the WGN. Geophones transmit data packets almost simultaneously during the geophone recording period of 5 s. This is a bottleneck for AODV as route discovery process is initiated whenever a node wants to transmit a packet, thereby overloading the network capacity with route request (RREQ) packets leading to collisions. This results in failure in route discovery process causing more packets to be dropped.

Figure 3 shows the average packet end-to-end delay in the network. As expected, the delay decreases with higher data rate as a lower data rate implies longer packet transmission time. The delay increases with increase in network size as a packet might travel over two or three hops. In addition, as the probability of collision increases with an increase in network size, packets will take longer time in the queue due to the CSMA/CA back-off algorithm, especially in AODV protocol during the route establishment process.

3 Conclusion

The preliminary study sets to investigate the performance of proactive and reactive protocols in WGNs, with focus on determining the optimal number of geophones that could be supported in a subnetwork. The initial results show that this clearly depends on the type of link layer technology (data rate, MAC) and the underlying routing protocols strategy. RPL and OLSR show more promising results as compared to AODV protocol. These protocols offer low delay during the route setup process as routes are immediately available when data transmission begins. However, high bandwidth requirement might be a major drawback in OLSR as the control overhead is proportional to the number of nodes in the network. RPL looks more promising in terms of cost effectiveness as it employs trickle mechanism to optimize the dissemination of topology control information over the network. Future work will be directed towards realizing the architecture presented in Figure 1 with enhancements to MAC scheme, e.g., dedicating the resources, and also to optimizing the routing strategy within the subnetworks.

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