Hierarchical High-speed No-blind Networks Used in Land Seismic Explorations

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***Abstract*—With seismic explorations developing quickly, traditional communicating technologies used in land seismic explorations expose more and more shortcomings. For example, conventional cable-based land exploration systems are very expensive, labor intensive and difficult to be laid down in complex terrain, while the cable-free ones have not been widely used in large-array and high-density land seismic explorations, which requires real-time data retrieve, for the limits of communication system. In order to realize real-time large-array high-density land seismic exploration everywhere, a high-speed communication system, which has a large area signal cover without bind zone, is needed to be set up. For this purpose, a network, we called Hierarchical High-speed No-blind Network (HHNN), is proposed. There are two layers, which are core network and extended network, in HHNN. Generally, core network, using LTE (Long Term Evolution) technologies, fulfills high-speed communication and a large area signal cover, while extended network, using self-organized network technology, make the exploration area no-blind. Core network can be set up by both the LTE network deployed by operators and the network deployed by the crew, using LTE technologies. Extended network can be organized without the crew's operation by adopting the multi-hop reliable communication protocol which is designed by this paper. As the test result showing, HHNN can basically be used to realize a real-time large-array high-density seismic data acquisition.**

Keywords—cable-less seismic exploration; LTE; self-organized network; hierarchical structure

I. INTRODUCTION

In last 30 years, the array of seismic exploration has become larger and larger, which is pushed by the unavoidable need for oil and gas. Moreover, it is generally believed that large-size systems under design are targeting more than 300K channels simultaneously active, moving to one million within the next decade. Conventional cable-based land exploration systems are based on telemetry cabling to handle control commands and to collect data samples from remote sensors in real-time. This solution is very expensive and labor intensive because it involves laying out many tons of cables. The use of cabling accounts for up to 50 percent of the total operating cost of a typical land survey and up to 75 percent of the total equipment weight[1-2]. Meanwhile, in some areas, it is difficult to lay down cables because of terrain, environmental concerns, non-permit areas, and barriers like highways and rivers. Also, HSE (health, safety and environment) exposure is high with cable-based land exploration systems[3]. However, cable-less seismic exploration systems, which overcome those problems mentioned above, have several other shortcomings. The most severe one is there is no cable-less system that can offer a real-time data collection (or real-time QC), as well as support more than ten thousands channels simultaneous exploration. So, it is very meaningful that researching the communication networks of cable-based land exploration systems and proposing a kind of networks which is able to meet the needs of real-time large-array high-density cable-less seismic exploration.

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II. HIERARCHICAL HIGH-SPEED NO-BLIND NETWORKS

A. Requirements of Communication System

A real-time large-array high-density seismic exploration consists of hundreds of thousands sensors, laid out roughly in the shape of rectangle, whose length and width usually are from several kilometers to a dozen more kilometers, with a receiver density of 2000-3000 channels/km^2. So, an ideal communication system of seismic explorations is needed to meet the following three requirements. First of all, range of communication should be up to 20 kilometers, in order to realize a long-distance communication of seismic exploration. Secondly, the number of communication network nodes is able to be hundreds of thousands, while the throughput of communication network should be nearly billions of bytes per second with 24-bit and 500Hz sampling in seismic exploration for real-time data collection. Thirdly, there should be no-blind zone in exploration area, which requests the communication system has the ability of transmitting data through obstacles such as hills, trees, vehicles etc..

However, there is no traditional network that could meet all of the three requirements. For example, a multi-hop network based Wi-Fi[4], which is used in RT System 2 researched and produced by Wireless Seismic, can solve the problem of long-distance communication at a cost of effective network bandwidth, which is directly associated with the effective network throughput. Because of this, RT system 2 can hardly realize a seismic exploration with more than ten thousand channels. As another example, an access-point network based on Wi-Fi, which is applied in Unite System, researched and produced by Sercel, can effectively utilize the bandwidth of communication network. Due to the access-point architecture and Wi-Fi standard, Unite System does not have the ability of communicating through obstacles and its longest communication distance is less than 2 kilometers[5]. Thus, Unite System meets neither the first requirement nor the third one. Considering frequently used seismic exploration system and common communication technology[6], a kind of hierarchical structure network which is high-speed and no-blind is proposed to meet all of the three requirements.

B. The Structure of Hierarchical High-speed No-blind Networks

To design a network satisfying all of these requirements, we put forward a kind of hierarchical network called hierarchical high-speed no-blind networks (HHNN), which includes two portions, as the Figure 1 shows. One is core network, the other is extended network. The core network should be designed to support real-time mass data collection in a large zone with a large number of network nodes, which is requested by the first two requirements. There are lots of subnets in the extended network, each of which includes an interface node that connects itself to the core network, thereby organizing the whole subnet. Every subnet in the extended network which accesses the core network by its interface node is responsible for making blind zone free seismic exploration

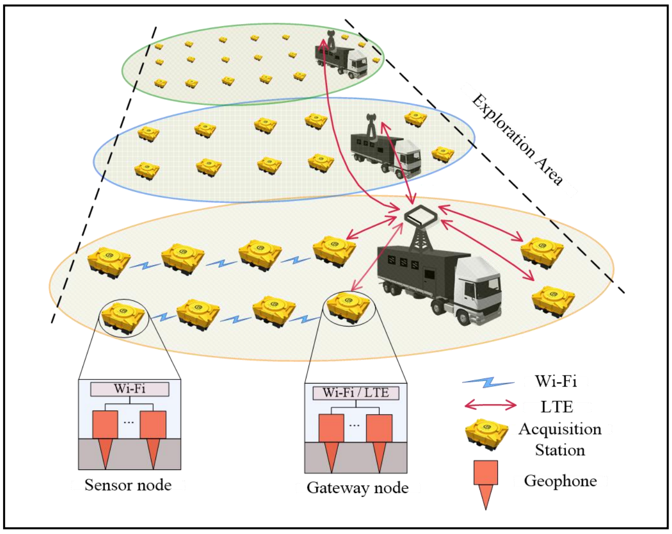

Fig. 1. The architecture of HHNN

To realize the core network's function, mobile communication networks used in cell phone's communication are one of the best choices of the core network which are able to accommodate a lot of nodes in a large area and have massive data transmission ability. Therefore, having been successfully applied in human's daily life, LTE (Long Term Evolution) network was chosen to be HHNN's core network. On the basis of extended network's demand, a kind of self-organized network based on multi-hop architecture has been designed. Because the multi-hop architecture is capable of communicating through obstacles and self-organized technology make the subnets composed without human operation, the self-organized network can easily provide us with high quality results over large area covered by different obstacles without being victimized by blind zones..

C. LTE Technologies for Core Network

According to the needs of core network, which are realizing large area signal cover and massive network throughput, it is feasible that utilizing the existing LTE network as HHNN's core network.

If exploration area is out of the LTE network or the LTE network is not able to accommodate so many nodes in a real-time way, we can set up our core network, which is like a simple LTE network. Two key technologies of the LTE have been chosen to be used in establishing core network, which are multicarrier technology and multiple-antenna technology. Multicarrier technology used in the LTE is OFDMA (Orthogonal Frequency-Division Multiple Access) for its high spectrum efficiency and functions of minimizing intra-cell interference as well as maximizing capacity. OFDM (Orthogonal Frequency-Division Multiplexing) divides the bandwidth available for communicating into a multitude of narrowband subcarriers, arranged to be mutually orthogonal, which either individually or in groups can carry independent information streams; in OFDMA, this subdivision of the available bandwidth is exploited in sharing the subcarriers among multiple users. Unlike LTE we used in daily life, in HHNN's core network established by ourselves, OFDMA is used in both uplink and downlink. Moreover, the bandwidth allocated to uplink is greater than the bandwidth allocated to downlink. This difference between standard LTE and core network established by ourselves is because the volume of our core network's data in uplink is much larger than that in downlink, while the amount of LTE's data in uplink is much smaller than that in downlink. The use of multiple-antenna technology allows the exploitation of the spatial-domain as another new dimension. This becomes essential in the quest for higher spectral efficiencies. As will be detailed in many literatures, with the use of multiple antennas the theoretically achievable spectral efficiency scales linearly with the minimum of the number of transmit and receive antennas employed, at least in suitable radio propagation environments. The LTE's multiple-antenna technology used in HHNN's core network is MU-V-MIMO (Multi-User Virtual Multiple-Input Multiple-Output), which used in uplink can not only boost the peak per-user data rate but also improve overall system capacity and spectral efficiency.

D. Self-organized Network Technology for Extended Network

The goal of self-organized network is to eliminate blind zone in exploration area. Each acquisition node in the rectangle array is equipped with a Wi-Fi module. Wi-Fi modules are configured in ad-hoc mode, which is a kind of self-configuring, decentralized network. If there is an obstacle in the exploration area that blocks the signal of core network, a subnet of extended network will be set up here. In the subnet, nodes in the blind zone transmit data by a multi-hop architecture, which is the most stable network structures in practice and easily organized. In this way, every node in the subnet of extended network can connect with the subnet's interface node mentioned above, also called the gateway node, which plays a role in connecting core network and extended network. This is how extended network we designed make the exploration area no-blind.

To make data transmitting faster, all the acquisition nodes must employ a lightweight, efficient and reliable communication protocol. Therefore, the design of communication protocols should be consistent with the principles of making transmission reliable, fast and cheaper resource of processors in the node. To realize a fast and stable self-organized network, there is a tree structure where father nodes at most have one child node and only accept the one that has the strongest strength of Wi-Fi signal in the unorganized nodes of the subnet as their only child node. Each node owns unique identification (ID) in the subnet, which represents its depth in the tree structure. All nodes only need to know their father and child and communicate with their father and child node by using their ID instead of IP address which needs more bits to save, send and accept. This routing method has the characteristics of less resource costing, fast network organizing and stable connecting. To ensure the reliability of data transmission and making the costing of communication less, a type of hop-by-hop reliable guarantee mechanism is applied in the extended network instead of the widely used Internet TCP or UDP, a kind of end-to-end reliable protocol. When using end-to-end reliable guarantee mechanism, destination nodes will request retransmission from source node if the data packet loss occurs in some node which is in the route of the data flow. In the extended network, there is still a lot of data to be collected, while the communication condition of extended network is usually terrible, because of the obstacles, where packet lost rate is often very high. So, in this case, the end-to-end reliable guarantee mechanism make the data frequently retransmit from source node when there is a packet loss in the data flow link, even it is successful that the transmission before the loss. By contrast, the hop-by-hop reliable guarantee mechanism we designed make reliable transmission check every hop rather than only in destination node. Thus, in this way, only the place where packet loss happens requests retransmission. Therefore, compared with traditional reliable guarantee mechanism used in TCP or UDP, the hop-by-hop reliable guarantee mechanism makes the extended network more efficiently and fast. Moreover, in order to make network transfer fluently and avoid that the large throughput of the extended network makes congestion occur, when workers collect seismic data, because of the limited wireless link bandwidth, every node detects whether the network congestive or not when it wants to send data. If the network is congestive, nodes will store the data in its buffer sequences until the network recovers.

By these methods, the communication protocol we designed, which used in self-organized network based on multi-hop architecture, meets all the requisitions of extended network.

III. Test Result

HHNN was tested in the mode, which uses the standard LTE network as its core network. Core network is the 4G network, which has the capacity of thousands of nodes per square kilometer while every node's average transmitting rate is above several million bits per second. So, the core network can meet the requirements mentioned above. The test results of HHNN's extended network are as follow: the distance between adjacent nodes is about 20m to 50m; the maximum hop count is 100; the average transmitting rate is between 400KB/s and 600KB/s.

IV. Conclusions

In this article we introduced the basic principles of land seismic acquisition systems from the communication perspective. A number of requirements for the wireless communication system are concluded in order to develop dense real-time no-blind networks for land seismic acquisition. The proposed HHNN, which is based on a hierarchical structure with different network technologies, can basically fulfill the all demands of present real-time large-array high-density cable-less seismic exploration in a convenient way, according to the test result of HHNN. However, two shortcomings exist in the HHNN. Firstly, there will be plenty of competition in core network, which decreases the efficiency of communication, when the acquisition stations' number becomes large. So, the research on core network is trying to utilize contention-free communication protocols to overcome this problem. Secondly, in the extended network, there is a communication bottleneck, especially when the maximum hop over 20. For this reason, compressed sensing is attempting to be used in the acquisition procedure of extended network, in order to decrease the redundancy of gathered data.

The recent technological advances in LTE and Wi-Fi suggest that the wireless community is now becoming mature enough to construct a fully wireless system for various large-scale and high-density sensor networks within the next few years.

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