Fog Computing as a Critical Link Between a Central Cloud and IoT in Support of Fast Discovery of New Hydrocarbon Reservoirs

Andrzej M. Goscinski[1,2](✉), Zahir Tari[2], Izzatdin A. Aziz[3],
and Eidah J. Alzahrani[2]

[1] School of Information Technology, Deakin University, Geelong, Australia
`ang@deakin.edu.au`
[2] School of Science, RMIT University, Melbourne, Australia
[3] Universiti Teknologi Petronas, Seri Iskandar, Malaysia

Abstract. The overall process of discovering hydrocarbon traps, starting with geological exploration through to Seismic Data Processing (SDP) is very expensive and time consuming. In the real-world, the oil and gas production relies on how soon seismic data is computationally processed. The ability for an oil and gas company to perform seismic computation at higher speed within shorter time provides competitive advantage in the race to discover new hydrocarbon reservoirs. We are convinced that the current state of research in areas such as cloud computing, fog computing, and edge computing will make a major change. The goal of this paper is to present the first step towards the development of such a three-level system and show its feasibility in the context of a model for hydrocarbon exploration and discovery operation.

Keywords: Seismic Data Processing (SDP)
Hydrocarbon exploration · Fog computing · Edge computing
Cloud computing

1 Introduction

Seismic data gathered from the Hydrocarbon Exploration and Discovery Operation is essential to identify possible hydrocarbon existence in a geologically surveyed area. However, the discovery operation takes a long time to be completed and computational processing of the acquired data is often delayed. Hydrocarbon exploration may end up needlessly covering an area without any hydrocarbon traces due to lack of immediate feedback from geophysical experts. This feedback can only be given when the acquired seismic data is computationally processed, analysed and interpreted timely. Therefore, we propose application of cloud technology and map it on a comprehensive model of facilitate Hydrocarbon Exploration and Discovery Operation using data collection, pre-processing,

J. Hu et al. (Eds.): MONAMI 2017, LNICST 235, pp. 247–261, 2018.
https://doi.org/10.1007/978-3-319-90775-8_20

encryption, decryption, transmission, and processing. The model exploits the logical design of Seismic Data Processing (SDP) that employs distributed systems and processing, and the ability for geophysical experts to provide on-line decisions on how to progress the hydrocarbon exploration operation, at a remote location, practically in the world of Internet of Things (IoT).

Many researchers are convinced that Fog Computing, is becoming the next big wave in computing due to the strong demand from IoT markets. As researchers of service computing, we are surrounded by numerous hypes and myths but also real opportunities of Fog and Edge Computing. It is time that we should have a clear understanding of the differences between the concepts of Fog and Edge Computing, and the role of Cloud datacentres in the new Fog Computing paradigm. In this paper, with a focus from service computing point of view, we regard Fog Computing as a critical link between a central cloud and IoT, and try to clarify these concepts and their relationships. The problem is how to apply the recently acquired knowledge and skills in clouds, fogs and IoT in the oil and gas discovery. We will show our mapping of these three-part computing technology on a Seismic Data Processing (SDP) model.

The main contributions of this paper are:

- A specification of the Seismic Data Processing in the terms of IoT
- Presentation of comparison and contrasts of fog computing and edge computing against IoT
- An original mapping of the clouds, fogs, edges on the IoT of the Seismic Data Processing model.

In this paper, Sect. 2 introduces basic concepts of hydrocarbon exploration and discovery their problems and solution requirements. Section 3 shows our model of Hydrocarbon Exploration and Discovery Operation, which demonstrates the IoT world of oil and gas exploration. Section 4 discusses and clarifies our approach to IoT and Clouds, in particular cloud, fog, and edge computing. Section 5 introduces our original mapping of clouds and fogs on IoT hydrocarbon exploration and discovery model. Section 6 concludes the paper.

2 Hydrocarbon Exploration and Discovery Operation Problems and Solution Requirements – IoT Perspective

2.1 Data Collection

Seismic Data Processing depends on data collection. In a typical marine survey, exploration vessel tows airguns as sources of shocks or signals. The vessels also tow a stream of receivers or hydrophones to gather signals reflections. The seismic reflection data carries the properties of the Earth's subsurface as the propagated signals are reflected with different acoustic impedance levels (Fig. 1). Then, the seismic data is collected and stored at site on board exploration of vessels.

The layout of signal generators and receivers in a marine-based geological survey operation is shown in Fig. 2. So, during a marine based geological survey

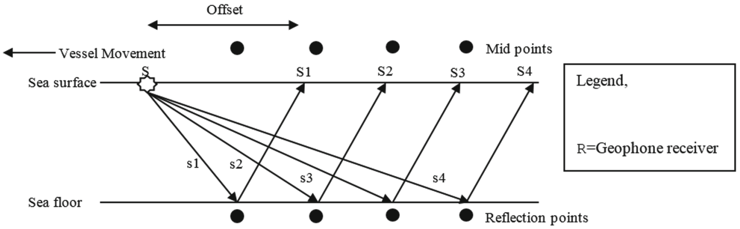

Fig. 1. Data collection - signal reflection and middle points are at the same time state.

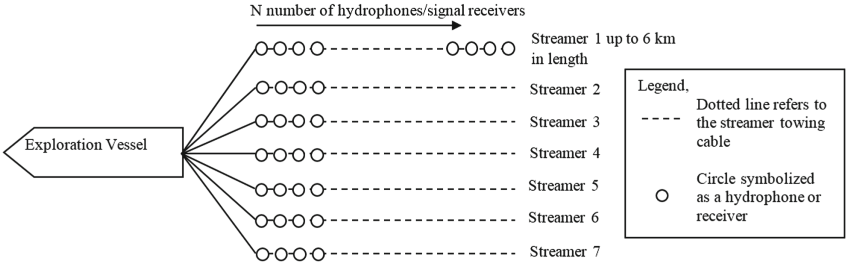

Fig. 2. Signal receiver deployment layout viewed from top.

operation, the 50 km^2 of surveyed area is translated from a 200-km offset of a moving hydrocarbon surveying vessel by 0.25 km width. A single vessel can tow more than 7 streamers of receivers in a parallel layout. Each streamer reaches up to 6000 m in length and consists up to 480 receivers. The number of receivers depends on the distance interval set between individual receivers. For instance, if the receivers are set at an interval of 12.5 apart from each other over the 6000 m stretch, a total of 480 receivers can be towed in one streamer. If a vessel tows up to 7 streamers, this means that a total of 3360 receivers are available to record incoming signal reflections from multiple directions (Fig. 1). Simultaneous signal readings gathered from the receivers towed by the streamers construct a higher dimensional seismic data representation. Signal reflections captured by the receivers from multiple angles and directions enable the construction of a seismic data encompasses different orientation and dimensions. Since the area covered by each single vessel is large, and the number of vessels is big, the amount of data collected is huge.

2.2 Hydrocarbon Exploration and Discovery Operation Problems and Solution Requirements

Oil and gas discovery depends on interpretation of collected data and feedback passed on to the vessels. Feedback can only be given when the acquired seismic data is computationally processed, analysed, and interpreted. In this section, we identify the issues of the current hydrocarbon exploration operation and a set of solution requirements, which form a basis of a model to address these issues.

A. Problems Identification

From our expert interview in [1], we have identified four existing problems in relation to the current hydrocarbon exploration and discovery practice.

1. Large Seismic Data Size
   Seismic data acquired during a 3-month hydrocarbon exploration operation can yield up to 1 PBytes in size. Seismic data consists of signal reflection points resembling the Earth subsurface and formations. A small scale 122 GBytes of seismic data can contain as many as 24 million signal reflections points. The large size of seismic data contributes to problems such as transmission and processing times.
2. Data Transfer
   Seismic data are being transported in tape drives by helicopters and runner boats from exploration sites to private centralized processing centres on a fortnightly basis [1], due to two reasons:
   (a) High Value of Seismic Data - These data are very expensive and the oil and gas companies do not tolerate losing such valuable datasets through security beaches during transmission [1].
   (b) Data Communication - The current wireless network infrastructures used by the hydrocarbon industries from remote exploration sites to the processing centres is limited in terms of bandwidth and communication speed to transmit seismic data [1,2].

   Therefore, a conventional approach of manually transporting seismic data to centralized processing centres to carry out SDP is still preferred. However, the trustworthiness of human agent responsible for delivery of the seismic data to the processing centres is also questionable, because can be disclosed to the companys competitors during the delivery process. Nevertheless, the cost in terms of time loses for conventional data transportation from the remote exploration site to the designated processing centres is high.

   The private processing centres possess state of the art HPC clusters [3]. Processing is carried out using commercial SDP software packages on these HPC clusters. Highly specialized commercial software packages for SDP are very expensive. According to [4], commercial SDP software packages are priced at \$3.15M (USD) for 5 licenses for a 5 year term.
3. Computation Time
   Seismic data acquired from the hydrocarbon exploration operation needs to be computationally processed to get a corrected signal reading. The computationally processed seismic data is interpreted by geophysical experts to identify any existence of a hydrocarbon reservoir. Computational processing consumes up to a few months when executed on a cluster computer or high-end machines [5]. According to [1], a computational time of one month is required to process 1 PBytes of industrial scale seismic data on a large HPC cluster, consisting of 128 nodes, with 1024 cores of processors.

4. Processing Cost
   The cost of processing the data is high. The current cost of SDP in private processing centres is approximately \$2k per km^2 seismic data [5]. A small-scale data acquired during a 1200 km^2 hydrocarbon exploration operation costs approximately \$2.4M. The SDP cost for 1200 km^2 can reach up to \$10M, depending on the complexity and granularity of the data.

B. Solution Requirements
In response, we propose a set of solution requirements to facilitate the Hydrocarbon Exploration and Discovery Operation.

1. Data Transmission
   The remote location of hydrocarbon exploration sites in the middle of the sea make it impossible to be linked using wired network. A satellite network [8] is opted for a real time transfer to allow ubiquitous SDP from remote exploration sites to the center. Satellite services are reasonably inexpensive when trading off with the urgency to transmit and process seismic data. An average cost for a commercial business package intended for a dedicated satellite transmission speed of 1 Gbps is approximately a \$4,6k per month [6,7].
2. Data Security
   Seismic datasets are valuable due to the high operational cost and the potential of hydrocarbon existence presented in the datasets. Data transfer over the wireless network is highly subjected to data stealing and eavesdropping. A natural way of securing data before transmitting over the network is through data encryption. A fast encryption method is necessary to allow huge seismic datasets to be encrypted in a short time.
3. Cost
   Minimizing cost in hydrocarbon industries is a priority. Although hydrocarbon industries appear able to afford the expensive computing infrastructure and software packages, it is always imperative to find ways to minimize cost. In hydrocarbon exploration and discovery, costs can be reduced using cloud and much cheaper open source SDP software packages and higher processing capability providing outcome in a shorter time [8].

3 Hydrocarbon Exploration and Discovery Operation Model

Having defined the problems and solution requirements in the current hydrocarbon exploration and discovery operation, there is a need for a model to address these problems and solution requirements. In this section, we present our proposed model of hydrocarbon exploration and discovery from data acquisition and satellite data transmission through to data processing and feedback. The model addresses the problems listed in Subsect. 2.2.A and satisfies the solution requirements in Subsect. 2.2.B. Figure 3 shows the general idea of the proposed hydrocarbon exploration and discovery operation model [9].

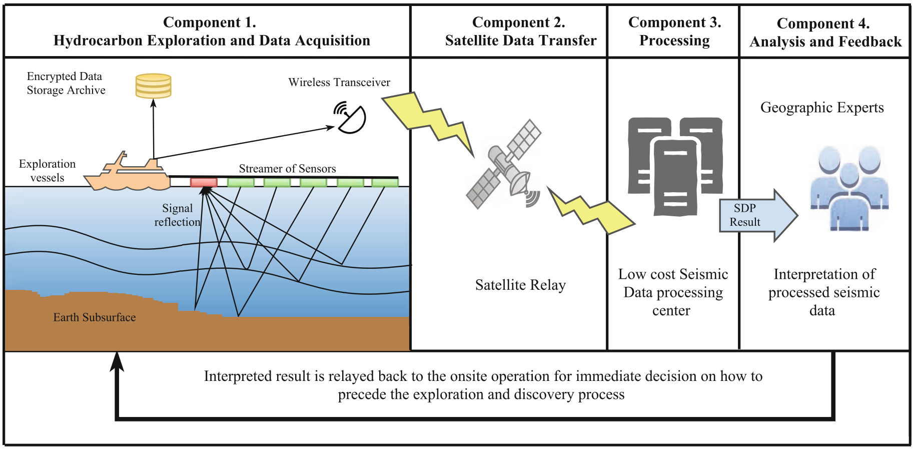

Fig. 3. The model of Hydrocarbon Exploration and Discovery Operation using CBS.

The model is consists of four components. They depict the operational sequence of seismic data acquisition, wireless transmission via the satellite to relay the acquired seismic data, the processing of seismic data in a low cost seismic data processing centre, and interpretation of the processed results by geophysical experts. The results are then relayed back to the onsite operation for immediate decision on how to proceed with the exploration and discovery operation.

Component 1: Hydrocarbon Exploration and Data Acquisition

The first component of the model comprises two sub-components that take place in the remote hydrocarbon exploration sites.

1. Data Collection and Storage
   Seismic data is continuously gathered from the acquisition process and stored on disk that resides at the remote exploration site. Marine hydrocarbon exploration involves generating acoustic signal reflecting through the Earth subsurface, which are gathered by a stream of signal receivers at the surface. Signal reflection travelling times are recorded and represented as seismic traces on a data collection unit on the exploration vessel to be stored in a storage archive. Seismic data are gathered in a raw SEGD format prior to transmission and later converted to a specific software package format for processing. SEGD is the recommended seismic data format by the Society of Exploration Geophysicists (SEG) for newly acquired data from the hydrocarbon exploration operation [10].
   Periodic transmission takes place when a threshold of approximately 50 km^2 block has been covered. The 50 km^2 approximation of geological survey is a representative value agreed by the hydrocarbon exploration contractors

to yield significant geophysical results when performing SDP [1,11,12]. The $50\,\text{km}^2$ of surveyed area is translated from a 200-km offset of a moving hydrocarbon surveying vessel by 0.25 km width. An area of $50\,\text{km}^2$ can be surveyed with a vessels speed of 6–10 knots or 11–18 kmh. The representative seismic data size encrypted prior to transmission.

2. Data Encryption
   A natural way of securing data to allow transmission across the globe is through encryption. In our design, as soon as the whole $50\,\text{km}^2$ block of data is acquired, an encryption process is performed. A symmetrical encryption method with high bit key is considered to provide fast encryption with high security [13]. The $50\,\text{km}^2$ of a geologically surveyed area can yield up to 10 GBytes of seismic data. A high end system is commonly placed at the exploration site for data collection and pre-processing [7]. The process of encrypting this size of data requires a high-end server with at least quad core processors on board of the exploration vessel. A symmetrical encryption method [14] through a high-end system of 3 GHz quad core processors can encrypt a 10 GBytes of data at a computational speed of 60 s [15].

Component 2: Satellite Data Transfer
The encrypted block of seismic dataset located on the remote data collection unit is now ready to be transmitted via a satellite network to the data processing centre for processing and analysis. The second component includes the transmission protocol and follows standards for the satellite data transfer.

1. Transmission Protocol
   High bandwidth satellites offer natural support for communication mobility to the Internet across the globe. The Transmission Control Protocol (TCP) has been proven to support reliable Internet communication over the satellite [16]. A proven application that leverages on the TCP protocol by transmitting data using the Internet broadband over the satellite network is the digital TV broadcasting service. This service uses fast satellite transmission of a theoretical maximum bit rate or transmission speed of 1 Gbps to relay large stream of data [17]. A similar concept is useful to apply in transmitting a large amount of seismic data used in the hydrocarbon industry.
2. Data Transfer via Low Earth Orbiting (LEO) Satellite Network using Ka-Band Frequency
   The breakthrough in satellite communication through the implementation of the Ka-Band frequency has made it possible to transmit large volume of data gigabytes in size. Ka-Band is a high resolution and focused microwave beam, which falls between the frequency ranges of 27.5 GHz and 31 GHz, initially used in military satellites, but has recently being commercialized. LEO satellite networks have been used to provide internet services on cargo and passenger vessels at a very high data transmission rate of 1.2 Gbps using the Ka-Band frequencies [18].

3. Wireless Standard: Worldwide Interoperability for Microwave Access (WiMAX)
   Recent breakthrough research has demonstrated the applicability of using the WiMAX wireless communication standard operating between inter-satellites and mobile Earth transceiver stations [1]. The WiMAX IEEE standard 802.16 can transmit at a speed of 1 Gbps for up to 50 km in distance without signal amplifier or a repeater. Only a small bit error rate occurred when transmitting data beyond the distance of 50 km up to 400 km [20]. High bit rate data transfer with long range network propagation have championed WiMAX in the usage of satellite networking.

Component 3: SDP on Low Cost Data Processing Centre

Seismic data gathered from the hydrocarbon exploration site is transmitted over satellite to the low-cost data processing centre. To minimize hydrocarbon exploration cost, the cost of processing seismic data needs to be significantly reduced.

The hydrocarbon industry does not need to acquire large processing facilities such as high-performance computers to perform seismic processing. The cost to maintain the computing infrastructure will be too high.

In our design, data processing centres are proposed to exploit clouds to perform SDP at a lower cost. Through clouds, computing infrastructure such as processors and storage can be leased out from the cloud providers, such as Amazon EC2 and Microsoft Azure. The concept of leasing computing infrastructure from the cloud providers released the burden from the hydrocarbon industry to pay for the overheads of maintaining the computing infrastructure.

Processing time for seismic data can be reduced significantly by adding more compute nodes and CPU cores [1]. Clouds computing technology offers scalable computing resources. On the other hand, a HPC cluster having only a fixed number of compute nodes is limited in terms of processing capability. Higher processing performance allow SDP to be executed in a shorter time [8].

An additional approach to reduce costs is using open source SDP packages, which incurs practically no cost. These SDP packages are installable on clouds [8]. Similar core seismic functions are available in both commercial and open source SDP packages. Commercial software packages contain seismic functions arranged in an integrated form featuring enhanced graphical layout. The enhancement of clouds to perform SDP will be discussed further in Sect. 5.

Component 4: Analysis Results

The accelerated processing on clouds allows immediate analysis and feedback by geophysical experts even from across the globe. The processed data can then be analysed and interpreted for any possible hydrocarbon existence. Immediate decision and feedback can be delivered to the onsite remote hydrocarbon exploration location to proceed with the surveyed area, or otherwise refocused to another area, which can be more promising.

4 IoT and Clouds

4.1 Cloud, Fog, and Edge Computing

Many enterprises and large organizations begin to adopt the IoT, sets of small devices, sensors and actuators that provide services to users directly at the edge using networks, wireless networks, in general the Internet. Users deal with huge amount of data, big data, collected from edges and used to control the edges. To take advantage of them they must be transferred from/to distant, sometimes very distant sources of these data to be stored and processed by data and compute clouds. Since direct service links between clouds and edges, as it is in the case of discovery of new hydrocarbon reservoirs, do not allow accessing large amounts of data quickly enough, safety could not be guaranteed, reliability could be jeopardized, availability cannot be completely provided, and the whole system is subject to security attacks, there is a need for a further improvement.

Due to sizes of enterprises and large organizations, some smaller clouds, which could be not only stationary but also mobile, and servers are being proposed to improve these metrics. This is where the concept of Fog, Edge, and Mobile Fog and Edge Computing comes to play. Cloud Computing, Fog Computing, and Edge Computing, are crucial activities for many enterprises and large organizations, and a critical process for the IoT. Business Insider stated a couple of month ago, that nearly $\$6T$ will be spent on IoT solutions in the following five years, and by 2020, 34 billion devices will be connected to the Internet, 24 billion within IoT [21]. Therefore, reaching this staggering figure depends just on both Fog Computing and Edge Computing.

There are examples of applications that due to data granularity collected and tasks allocated on the one hand, e.g., on a data collecting ship of a flotilla of oil and gas discovery ships in a city, county or a production division of a metallurgical plant, and finite power and storage capacity of (Mobile) Edge Clouds providing services on the other hand, require cooperation and coordination that has to be provided at the level that is lower than that provided by services at the Central Cloud level. These Central Clouds usually are located at fair distances from Edge Clouds. The problems of Edge Clouds and IoT devices shows up again, only at a higher abstraction level. And, this is where the concept of Fog, and Fog Computing comes to play the latest computing paradigm to support IoT applications, such as oil and gas discovery.

There are a lot of discussions and confusions around what is Cloud Computing, Grid Computing, Utility Computing, and Grid Computing 2.0. The history tells us it takes some time for people to really understand the differences and make clear definitions, but it did not prevent the advancing of the new technologies. In fact, these differences and definitions will become much clearer only after many successful applications and use cases have been produced. Therefore, in this paper, we are not trying to make solid definitions but rather than stimulate more discussions by proposing our own understanding of what are they and their relationships from the service computing point of view.

In the following, we will present a reference architecture for Fog Computing to further illustrate the concepts of Fog Computing and its relationships with Edge Computing and central clouds.

4.2 Fog and Edge Cloud Computing: Concepts and Relationships

The main confusion is the difference between Fog Computing and Edge Computing. We start with looking at the descriptions of Fog Computing and Edge Computing from major research venues.

IEEE Transactions on Service Computing Special Issues on Fog Computing [22]: The emerging Internet of Things (IoT) and rich cloud services have helped create the need for fog computing (also known as edge computing), in which data processing occurs in part at the network edge or anywhere along the cloud-to-endpoint continuum that can best meet user requirements, rather than completely in a relatively small number of massive clouds.

From the 1st IEEE International Conference on Fog and Edge Computing [23]: To satisfy the ever-increasing demand for Cloud Computing resources, academics and industry experts are now advocating for going from large-centralized Cloud Computing infrastructures to smaller ones, massively distributed at the edge of the network. Referred to as “fog/edge computing”, this paradigm is expected to improve the agility of cloud service deployments in addition to bringing computing resources closer to end-users.

From OpenFog Reference Architecture for Fog Computing by OpenFog Consortium [24]: Fog computing is a horizontal, system-level architecture that distributes computing, storage, control and networking functions closer to the users along a cloud-to-thing continuum. Fog computing also is often erroneously called edge computing, but there are key differences. Fog works with the cloud, whereas edge is defined by the exclusion of cloud. Fog is hierarchical, where edge tends to be limited to a small number of layers. In additional to computation, fog also addresses networking, storage, control and acceleration.

From the 1st IEEE International Conference on Edge Computing [25]: “Edge Computing” is a process of building a distributed system in which applications, computation and storage services, are provided and managed by (i) central clouds and smart devices, the edge of networks in small proximity to mobile devices, sensors, and end users; and (ii) others are provided and managed by the center cloud and a set of small in-between local clouds supporting IoT at the edge.

Apparently, there are two different views on the concepts of Fog and Edge Computing. Some researchers regard Fog and Edge Computing as the same paradigms with different names (as shown in [22,23]), while others distinguish between these concepts as two different things (as shown in [24,25]). We support the latter. Here we present our descriptions of Fog Computing as follows.

“Fogging” is a process of building a distributed system in which some application services, computation and storage, are provided and managed between Central Clouds and at the edge of a network in small proximity to mobile devices, sensors, and end users, by smart devices, even small local Edge Clouds, but others are still provided and managed by the in-between and/or Central Cloud; this allows for Fog Computing. So, Fog Computing is a middle layer between the cloud and edge, hardware and software that provide specialized services.

The research on Fog Computing is to address the problem of how to carry out such a "fogging" process, e.g., how to manage the whole system, how to define and create fogs, provide Fog Computing (compute, store, communication) services. Many of these problems have not been defined yet, the whole Fog Computing is not defined; there are very many open problems.

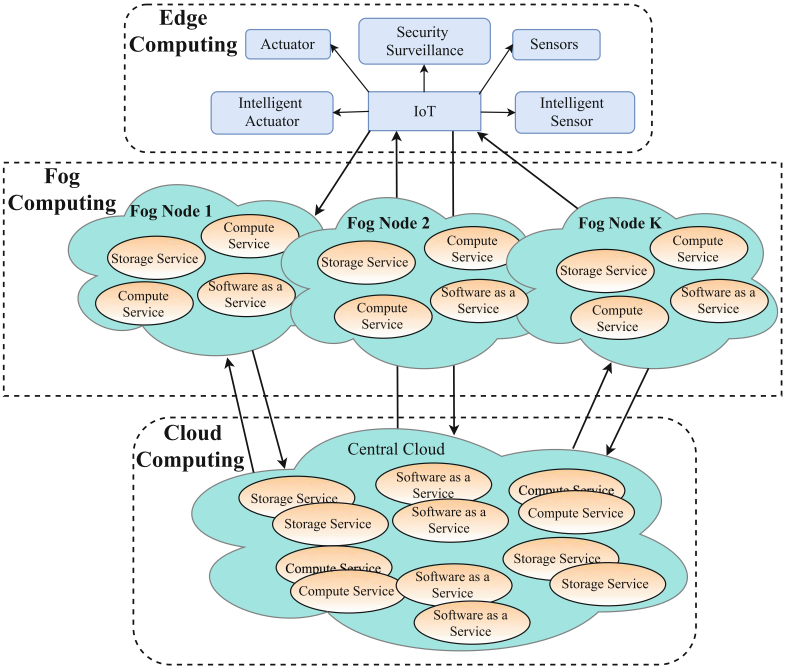

Fig. 4. IoT World - Cloud, Fog, and Edge computing architecture.

As shown in Fig. 4, Fog Computing, a part of the cloud stack, is the comprehensive computing paradigm that supports all sorts of IoT applications. Given the nature of different IoT applications and their requirements on computation resources such as compute, storage and software services, and their QoS constraints such as response time, security and availability, IoT applications may need to communicate with edge nodes only, or central clouds only, or both at the same time. Fog Computing can dynamically and seamlessly support all the three computing paradigms, viz. Edge Computing, Cloud Computing, and Fog Computing. Clearly, the major difference between Edge and Fog Computing is whether central clouds are included.

In summary, Edge Computing emphasis on processes at the "edge" and communication with the edge, while Fog Computing is carried out between the Central Cloud and the world of Edge Clouds, and thus includes the Edge. Fog

Computing services collaborate with and/or coordinate the cloud, the edge and the “world of IoT”, such as to play the roles of service providers, requesters, brokers, and so on. Thus, Fog Computing and Edge Computing have unique research topics as well as some overlapping topics. They form important subject area in research and practice. They are currently active and predictably booming soon. Their applicability in oil and gas discovery is discussed in Sect. 5.

5 Mapping Clouds and Fogs on IoT Hydrocarbon Exploration and Discovery Model

A description of the components of the Hydrocarbon Exploration and Discovery Model [8] shows methods used to identify potential locations of oil and gas and the four major components that were proposed to be designed, developed, and deployed using the technologies offered by Cloud Computing. However, a need for faster and cheaper discovery of oil and gas locations on the one hand and the development of new disruptive technologies in the areas of IoT, and Cloud and Mobile (Fog and Edge) Computing have generated an opportunity for the revision of mapping on these technologies on the Hydrocarbon Exploration and Discovery Model. The revised model is presented in Fig. 5. One of the most significant changes to the 2012 model is a new stage of processing based on the Fog Computing. We propose that a fog cloud could be deployed on one of the

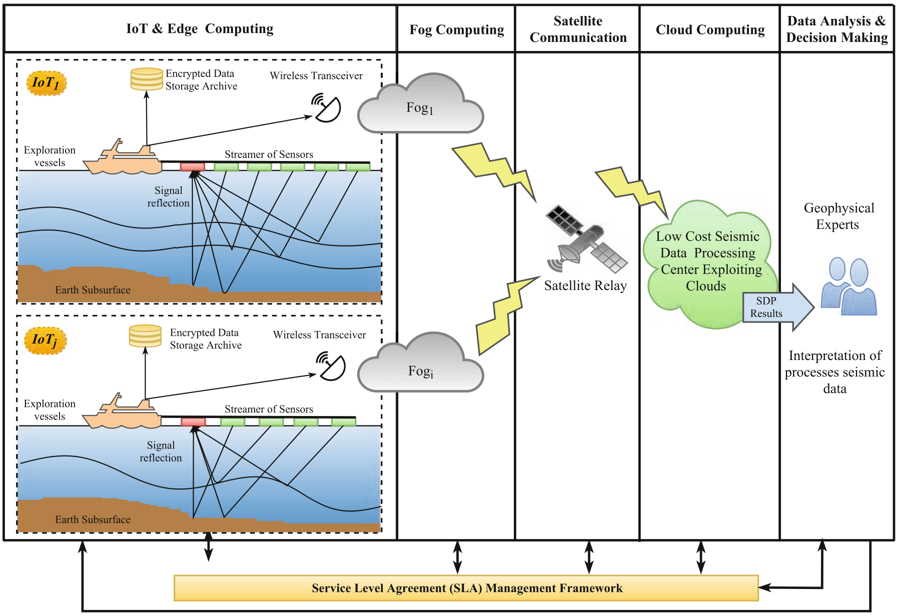

Fig. 5. Mapping Clouds and Fogs on IoT exploration model.

vessels; fog computing carried out by this cloud is made responsible for dealing with big data and their fast encryption.

The innovative features of this model are: (i) application of IoT features; (ii) exploitation of Edge Computing supported by fast wireless transmission (G4 and G5); (iii) intelligent big data pre-processing; (iv) increasing processing power at the lower level of exploration data processing using Fog Computing supported by interconnected Fog Clouds; (v) application of stronger security countermeasures; and finally (vi) generation of faster feedback provided to individual vessels. All these features make oil and gas discovery faster, less expensive, more secure, and leading to making bigger profits.

The final achievement of this project is its validation of our cloud stack presented in Sect. 4, in particular making a clear distinction between Fog Computing and Edge Computing.

6 Conclusion

The IoT applications are acquiring data using different types of end devices (or Things) such as mobile phones, sensors, actuators, vehicles, and other devices. These end devices can talk to the Edge nodes that are extensions of the traditional network access nodes equipped with additional computing resources and server-side software services to handle the requests of end devices or push services and information to end devices. These edge nodes often need to work collaboratively to fulfil some service requested by moving objects such as people and vehicles. End devices can also talk directly to the central clouds that can provide much more diverse software services and unlimited computing resources.

Fog computing facilitates the computing continuum from end devices to the cloud. As for how far the continuum needs to reach, it is decided by the requirements of the applications. As shown in Fig. 4, the distance to the end devices is becoming farther and farther from the edge to the cloud, and they are connected through different communication network channels with different speed and bandwidth. Meanwhile, the processing power is becoming greater and stronger from the edge to the cloud. Therefore, normally if the applications require faster response time and less computation, fog clouds should be powerful enough to handle the service requests. However, if the applications require a lot of computation and the access to very large datasets, these service requests should be sent to cloud data centres either directly from the end devices or through the fog nodes after pre-processing. It should also be pointed out that in many cases the fog and central cloud can work between each other to optimize system performance and improve service quality.

In this paper, we have presented our views on the concepts of Fog Computing and its relationships with Edge Computing and Cloud Computing. The key pint we want to emphasize here is to regard Fog Computing as a critical link between Central Clouds and IoT. We hope this paper could help to clarify some key concepts in Fog Computing, while in the meantime, stimulate more discussions and interests in the research and application of Fog Computing.

Acknowledgments. The authors wish to express their gratitude to Dr. Xiao Liu for making constructive comments to early versions of the paper. The authors would also like to thank the ARC (Australian Research Council) for the support of this project, under the Linkage scheme (LP#150101213).

References

1. Ibrahim, N.A.: Expert Interview Session with Senior Geophysicist: Seismic Data Acquisition and Processing, Private Communication (2010–2012)
2. SpectrumData. The Seismic Data Graveyard (2011, 7 July 2011). http://www.spectrumdata.com.au/content.aspx?cid=274
3. Lefebvre, J.: Geocomputing Services and Solutions: Presentation of GSS services and Geocluster overview. CGGVeritas (2009)
4. Seismic Micro-Technology Inc.: Cost, Saving and Analysis Results. Seismic Micro Technology Kingdom Return on Investment (ROI) (2010, 7 July 2011). http://www.seismicmicro.com/roi/roi_sample.htm
5. Technip: Oil and Gas Exploration and Production Reverse, Cost and Contract. Edition Technips, Centre Economic Paris (2007)
6. Ground Control: Satellite Internet Plans and Pricing: Satellite Internet Services From Ground Control (2011, 7 July). http://www.groundcontrol.com/satellite_internet_service.htm
7. HughesNet: Broadband Satellite Plans and Pricing. Hughes Network Systems (2011)
8. Aziz, I.A., Goscinski, A.M., Hobbs, M.M.: Performance evaluation of open source seismic data processing packages. In: Xiang, Y., Cuzzocrea, A., Hobbs, M., Zhou, W. (eds.) ICA3PP 2011. LNCS, vol. 7016, pp. 433–442. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-24650-0_37
9. Aziz, I.A., Goscinski, A.M., Hobbs, M.: In support of hydrocarbon exploration and discovery using clouds. In: International Conference on Computer & Information Science (ICCIS), vol. 2. IEEE (2012)
10. Yilmaz, Ö.: Seismic Data Analysis: Processing, Inversion, and Interpretation of Seismic Data. Society of Exploration Geophysicists (2001)
11. Barakat, S.: Seismic acquisition system. U.S. Patent No. 7,573,782, 11 August 2009
12. Ashton, C.P., et al.: 3D seismic survey design. Oilfield Rev. **6**(2), 19–32 (1994)
13. Elminaam, D.S.A., Kader, H.M.A., Hadhoud, M.M.: Performance evaluation of symmetric encryption algorithms. IJCSNS Int. J. Comput. Sci. Netw. Secur. **8**(12), 280–286 (2008)
14. Fujisaki, E., Okamoto, T.: Secure integration of asymmetric and symmetric encryption schemes. In: Wiener, M. (ed.) CRYPTO 1999. LNCS, vol. 1666, pp. 537–554. Springer, Heidelberg (1999). https://doi.org/10.1007/3-540-48405-1_34
15. Lafourcade, P., et al.: Symetric Encryption. Laboratoire Verimag Centre Equation, Private Communication (2008)
16. Arnal, F., Gayraud, T., Baudoin, C., Jacquemin, B.: Ip mobility and its impact on satellite networking. In: Advanced Satellite Mobile Systems, ASMS, pp. 94–99 (2008)
17. Shoji, Y., Takayama, Y., Toyoshima, M., Ohta, H.: Transparent transportation of digitized microwave environments over 10 Gbps optical networks: transportation of multi-channel digital broadcast signals. In International Conference on Transparent Optical Networks (ICTON), pp. 1–4, June 2010

18. Giffin, G., et al.: Satellite communications system for providing global, high quality movement of very large data files. U.S. Patent No. 7,783,734, 24 August 2010
19. Giuliano, R., Luglio, M., Mazzenga, F.: Interoperability between WiMAXand broadband mobile space networks [topics in radio communications]. IEEE Commun. Mag. **46**(3) (2008)
20. Zangar, N., et al.: Design, mobility management and analysis of a hybrid WiMAX/satellite network. In: IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications. IEEE (2009)
21. Here's how the Internet of Things will explode by 2020. http://bit.ly/internet_of_things_forecasts_business_opportunities
22. IEEE Transactions on Services Computing - A Special Issue on Fog/Edge Computing and Services. https://www.computer.org/cms/transactions/cfps/cfp_tscsi_fcs.pdf
23. 1st IEEE International Conference on Fog and Edge Computing, ICFEC 2017, Madrid, Spain, 14–15 May 2017. IEEE Computer Society (2017). ISBN 978-1-5090-3047-7. http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=8014314
24. OpenFog Reference Architecture for Fog Computing by OpenFog Consortium. https://www.openfogconsortium.org/
25. Goscinski, A.M., Luo, M. (eds.): Proceedings of 1st IEEE International Conference on Edge Computing, Hawaii, 25–30 June 2017