VOID AVOIDANCE ENERGY EFFICIENT PRESSURE-BASED OPPORTUNISTIC ROUTING FOR UNDERWATER WIRELESS SENSOR NETWORKS

BASHIR ABDULLAHI

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Faculty of Engineering
Universiti Teknologi Malaysia

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ABSTRACT

Underwater Wireless Sensor Networks (UWSNs) is considered promising technology for collection of data from underwater environment. It consists of energy limited nodes. Acoustic links is the most reliable medium of communication. Energy consumption is much high when it comes to transmission and reception of packets. The most challenging problem in UWSN is routing data packets successfully with minimum energy consumption and high packet delivery ratio. UWSNs is characterized with unique features such as dynamic topology, very high propagation delay, extreme energy consumption and high packet loss. However, Opportunistic routing (OR) is one of the promising approaches that can work efficiently in underwater. An energy efficient opportunistic routing algorithm should be used to handle efficiently the three main problem of UWSNs. The issues are selecting best forwarding node, communication void and duplicate forwarding suppression. Therefore, the research is to design and develop void avoidance and energy efficient pressure-based routing for UWSNs. To deal with improper selection of next forwarding node, Best Forwarding Node Depth Based Routing (BFNDBR) algorithm is introduced to select the best next forwarding nodes using node information based on sorting nodes and selecting the highest residual energy and highest link quality node. Then the BFNDBR is improved to tackle communication void. As the result the Void Avoidance Depth Based Routing (VADBR) algorithm is presented to detect void and trapped nodes and avoid them in packet forwarding process. Finally, The VADBR algorithm is modified and improved to deal with duplicate forwarding suppression. Therefore, Duplicate Packet Forwarding Suppressor Depth Based Routing algorithm (DPFSDBR) is introduced to improve efficiency of overhear and suppression algorithm by introducing dynamic forward selection method. To evaluate the performance of the proposed algorithms, AquaSim an NS2 based simulator was used as network simulator and 50 runs of experiments were conducted, and results were compared with existing algorithms. The results indicate that the introduced algorithms outperform others in terms of total energy consumption (27% - 42%) and packet delivery (2% - 16%) and network lifetime (20% - 40%).

ABSTRAK

Rangkaian Sensor Tanpa Wayar Bawah Permukaan Air (UWSNs) dianggap sebagai teknologi yang berharapan bagi pengumpulan data dari persekitaran bawah permukaan air. La terdiri daripada nod-nod bertenaga terbatas dan pautan akustik. Pautan akustik adalah medium komunikasi yang paling boleh dipercayai. Penggunaan tenaga adalah lebih tinggi apabila ia menyalurkan penghantaran dan penerimaan paket. Masalah yang paling mencabar di UWSN adalah penghalaan paket data dengan jaya dengan penggunaan tenaga minimum dan nisbah penghantaran paket yang tinggi. UWSNs bersifat dengan ciri-ciri unik seperti topologi dinamik, lengahan penyebaran yang sangat tinggi, penggunaan tenaga yang melampau dan kehilangan paket yang tinggi. Walau bagaimanapun, penghalaan Opportunistik (OR) adalah salah satu pendekatan yang dipercayai yang boleh berfungsi dengan cekap di bawah permukaan air. Algoritma penghalaan oportunis yang cekap tenaga harus digunakan untuk mengendalikan tiga masalah utama UWSN dengan cekap. Isu-isunya adalah pemilihan nod untuk pemajuan , komunikasi tidak sah dan duplikasi penyingkiran pemajuan. Oleh itu, penyelidikan adalah untuk merekabentuk dan membangunkan penghalaan penghindaran kekosongan yang berasaskan tekanan yang cekap tenaga untuk UWSNs. Untuk menangani pemilihan nod penghantaran berikutnya yang tidak wajar, algoritma Best Forwarding Node Depth Based Routing (BFNDBR) diperkenalkan untuk memilih nod terbaik menggunakan maklumat nod berdasarkan susunan nod dan memilih tenaga sisa tertinggi dan nod yang memiliki kualiti pautan tertinggi. Kemudian BFNDBR diperbaiki untuk menangani komunikasi yang tidak sah. Akibatnya, algoritma Void Avoidance Depth Based Routing (VADBR) dicadangkan untuk mengesan dan mengelakkan nod kosong dan terperangkap dalam proses penghantaran paket. Akhirnya, algoritma VADBR diubah dan diperbaiki untuk menangani penyingkiran pemajuan duplikasi. Oleh itu, algoritma Routing Based Upwarding Packet Forwarding Packet Duplicate (DPFSDBR) diperkenalkan untuk meningkatkan kecekapan algoritma pendengaran dan penyingkiran dengan memperkenalkan kaedah pemilihan bawa hadapan dinamik. Untuk menilai prestasi algoritma yang dicadangkan, simulator AquaSim berasaskan NS2 digunakan sebagai simulator rangkaian dengan 50 eksperimen dijalankan, dan hasilnya dibandingkan dengan algoritma yang sedia ada. Hasilnya menunjukkan bahawa algoritma yang diperkenalkan mengatasi yang lain dari segi penggunaan tenaga (27% -42%) dan penghantaran paket (2% -16%) dan jangka hayat rangkaian (20% -40%).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AHP	-	Analytical Hierarchy Process
AMCTD	-	Optimized Adaptive Mobility of Courirer Nodes Threshold DBR
ANP	-	Analytical Network Process
AODV	-	Adhoc on Demand Distance Vector Routing
AquaSim	-	Aquatic Simulator
AUV	-	Autonmous Underwater Vehicles
CBR	-	Constant Bit Rate
CI	-	Consistency Ratio
CV	-	Communication Void
DBRMR	-	Depth Based Multi Hop Routing
DBR	-	Depth Based Routing
DFR	-	Directional Flooding Based Routing Protocol
DSDV	-	Destination Sequence Distance Vector
EEDBR	-	Energy Efficient Depth Based Routing
EEF	-	Energy Efficient Fitness Based Routring
EEPR	-	Energy Efficient Pressure Based Routing
EPA	-	Expected Packet Advance
ERP2R	-	Energy Efficient Routing Protocol Based on Physical Distance and Residual Energy
ETX	-	Expected Transmission Count
FBR	-	Focussed Beam Routing Protocol
GPS	-	Global Positioning System
LCOR	-	Least Cost Opportunistic Routing
MAC	-	Media Access Control
NS	-	Network Simulator
OTcl	-	Object Oriented Tool Command Language
QoS	-	Quality of Service
RSS	-	Received Signal Strength
TCL	-	Tool Command Language

TWSN	-	Terrestrial Wireless Network
UWSN	-	Underwater Wireless Sensor Network
VAEEPR	-	Void Avoidance Energy Efficient Pressure Based Routing
VAPR	-	Void Aware Pressure Based Routing
VBVA	-	Vector Based Void Avoidance
WSN	-	Wireless Sensor Network

CHAPTER 1

INTRODUCTION

1.1 Motivation

The entire earth surface is divided into two. More than 70% is water and the rest are land. Mankind has explored most part of the land but know little about the underwater environment. This has arisen because of factors such as large area coverage, excessive pressure and harshness of the underwater (Ayaz, Baig, Abdullah, & Faye, 2011; Kheirabadi, 2015). Network that is employed on the land is called Terrestrial while that of water environment is referred to as underwater. Advancement in technology has made military and civilian applications are been integrated with Wireless Sensor Networks (WSN). This has dramatically changed and improved the applications (Kheirabadi, 2015; Yick, Mukherjee, & Ghosal, 2008). This advancement in WSN motivates scientist to transfer this technology to underwater, which they proposed Underwater Sensor Networks (UWSN) (Kheirabadi, 2015).

UWSN are comprised of self-organizing sensor and several autonomous nodes. The nodes are distributed manually or randomly in different position of underwater surroundings to collect data from underwater (Kheirabadi & Mohamad, 2013). Afterwards, acoustic waves transmit the data sensed to the destination(s) which are on the water surface. Normally, acoustic channels are equipped with acoustic modem for communication with one another and sink plays two roles as collector and transmitter of data. It collects through acoustic modem data from underwater and transfer to broadband station via radio waves (Kheirabadi & Mohamad, 2013). Various aspects interest the researchers in the development in UWSN such as security, localization and routing protocols.

There are challenges facing UWSNs which contribute to draw back of the system. The first one is high and low radio frequency. The later demands a very large antenna and the former is been absorbed by water quickly (Kheirabadi, 2015; Kheirabadi & Mohamad, 2013). The nodes are dispersed as the result of continual movement of the water. Therefore, optical waves are not efficient. They tend to scatter everywhere. The most suitable medium used in underwater is acoustic wave. It really performs well (Kheirabadi, 2015; Lu, 2016). Secondly, because of acoustic channel is asymmetric other challenges in acoustic application in communication emanates high propagation delay, packet loss, energy consumption and low bandwidth (Guo et al., 2008).Third, the sensor nodes in underwater are scattered everywhere as the result of water current. This alters the topology of the network seriously (Guo et al., 2008). Fourth, three dimensionality of UWSNs, exorbitant equipment and dynamic topology cause sparse topology (Kheirabadi, 2015). Fifth, the Global Positioning System (GPS) is not applicable in underwater as the result of fast absorption of radio frequency underwater (Ayaz et al., 2011; Kheirabadi, 2015).

As the result of inapplicability of properties of terrestrial wireless sensor network (TWSN), sensor nodes and their protocol in UWSNs, cannot be directly applied to underwater. We only adapt the features of TWSNs in terms of hardware and software to UWSNs. This marked UWSNs to be a different research area, and therefore, research started newly (Kheirabadi, 2015). Numerous researches have been conducted in the area like routing, MAC protocol, physical channel, localization (Kheirabadi, 2015) and void handling (Ghoreyshi, Shahrabi, & Boutaleb, 2017b). Although many researches have been carried out in communication void any of them have merits and demerit. Hence, there is still room for researches to come up with more techniques to deal with void communication more conveniently, packet forwarding efficiently and minimizing total energy consumption. There is still need to design a protocol that resolves cater for the above protocol requirements efficiently.

1.2 Problem Background

An UWSNs is 3D topology with sink(s) at the water surface. The sink(s) are communicating with underwater via acoustic modem and with offshore via radio frequency (RF) (Ghoreyshi et al., 2017b). Data are collected by sensor nodes which are scattered and transmitted them to sink(s) via relay nodes. Each forwarding node transmits packets to closer node than itself to sink (Ghoreyshi et al., 2017b). Discovering and maintaining full path from the source node to the sink is not needed. This makes the protocols scalable when it is to be applied to large networks with many nodes. What is required solely is maintaining information of one-hop or two hops in each node (Ghoreyshi, Shahrabi, & Boutaleb, 2017a). These nodes get empowered by only one source which is battery (Ayaz et al., 2011). As a result, the nodes suffer from energy problems (Ayaz et al., 2011). Unlike TWSN, energy consumption regarding transmission and reception in UWSN has been increased as the result of acoustic waves medium (Casari & Zorzi, 2011). Therefore, packets transmission and reception consume most of the energy in underwater sensor nodes (Ayaz et al., 2011; Pantazis, Nikolidakis, & Vergados, 2013). Routing in UWSN is the major part that has the responsibility to forward and receive the data packets (Melodia, Kulhandjian, Kuo, & Demirors, 2013; Yan, Shi, & Cui, 2008). To minimize energy consumption in any routing algorithm, some procedures must be put in place. An energy efficient routing algorithm must be designed to decrease total energy consumption and in packet forwarding it must select the most energy efficient and reliable nodes (Jouhari, Ibrahimi, Benattou, & Kobbane, 2016; Liu, Zhang, Mouftah, Shen, & Ma, 2009). UWSN is characterized with highly prone to error links and high propagation delay. These two characteristic make the opportunistic routing technique to be employed in most of the existing routing algorithms (Schaefer, Ingelrest, & Vetterli, 2009).

1.2.1 Opportunistic Routing (OR)

Opportunistic Routing (OR) selects the next forwarding nodes in hop-by-hop manner, therefore, it is proposed to take advantage of broadcast nature of wireless medium. Any node that has the ability to act as the best forwarding node will be given the priority (N. Chakchouk, 2015). OR utilizes flooding technique which achieves high throughput and packet delivery ratio but consumes high energy (Darehshoorzadeh & Boukerche, 2015). Accuracy and carefulness must be considered in designing the opportunistic routing algorithm so as to decrease energy consumption and provide high packet delivery ratio. To this end, different energy efficient and reliable opportunistic routing protocol have been proposed by (Huang et al., 2011), (Ashrafuddin, Islam, & Mamun-or-Rashid, 2013) and (Jafri, Ahmed, Javaid, Ahmad, & Qureshi, 2013). All existing protocols in underwater are classified into location based and location free. In location based protocols the next forwarding nodes is selected based on location information provided by GPS, which is costly and having high network overhead and high energy consumption (Ayaz et al., 2011; A. Wahid & Kim, 2010). The second protocol is location free. Energy efficient location-free category does not require the position information of nodes and are classified into two beacon- based and pressure-based. In the beacon-based, each node needs topology information to select the next forwarding node, while finding this information in mobile UWSNs imposes high overhead and high energy consumption to network.(Yan et al., 2008). The pressure-based routings do not impose extra overhead and energy consumption for the selection of next forwarding node. Consequently, due to limited energy source, the pressure-based routing algorithms are more promising routing methods in terms of energy efficiency. Therefore, this research is focused on designing an energy efficient pressure-based routing algorithm for UWSNs (Yan et al., 2008).

1.2.1.1 Next Forwarding Nodes Selection

The working efficiency that reduces energy consumption is termed energy efficiency, while reliability refers to ensuring data delivery during forwarding process. Both energy efficiency and reliability work on reducing energy consumption with consideration on packet delivery ratio (Pantazis et al., 2013). In opportunistic energy efficient and reliable routing protocols, next forwarding nodes selection is the first paramount part that has direct effect on energy consumption and packet delivery ratio. Additionally, the next forwarding node have been selected based on selected metrics. The best node forwards the data packets immediately, and the rest of the nodes hold the data packets in some algorithms. The lower nodes forward the same packet if the computed holding time finished and the node did not overhear forwarding the same packets. Many forwarding node selection algorithm have been proposed by (A. Wahid & Kim, 2010) and (Yan et al., 2008) to decrease the energy consumption and improve the reliability in opportunistic routing protocols in UWSNs. Most of existing location-based and beacon-based algorithms employ different metrics to select the next forwarding node, which are obtained from position information and topology information, respectively. However, finding this information wastes the energy of nodes. In addition, some of the existing pressure- based routing algorithms rank the nodes based on depth or hop count information to reduce the number of hop and decrease the energy consumption (Noh, Lee, Wang, Choi, & Gerla, 2012; Yan et al., 2008). EEPR(A. Wahid & Kim, 2010) uses residual energy to balance the energy of nodes and increase the network lifetime. Furthermore, some algorithms compute a weight based on depth and residual energy to jointly consider the hop count and energy balancing (Guangzhong & Zhibin, 2010; Jafri et al., 2013). Link quality is another vital metric that has a direct impact on increasing the packet delivery ratio and reduces the energy consumption (Diamant, Bucris, & Feuer, 2016; Zhang, Li, & Chen, 2013). In location-based routing protocol, Directional Flooding-based Routing (DFR)(Daeyoup Hwang, Dongkyun Kim, Hwang, & Kim, 2008) utilizes link quality metric, Expected Transmission Count for selecting the next forwarding nodes to improve the reliability. Reliable and Energy-Efficient Routing (R-ERP2R) (A. Wahid & Kim, 2010) which is a beacon-based enhances the reliability and minimizes the energy consumption by employing residual energy along with link quality for choosing the next forwarding node. Nevertheless, there is still need to develop a reliable energy efficient algorithm that selects the next forwarding node so that it reduces the energy consumption while providing a reasonable packet delivery ratio.

1.2.1.2 Duplicate Packet Forwarding

Duplicate packet forwarding is one of main issues in opportunistic routing algorithms, which increase network traffic and the energy consumption (Bayrakdar, Meratnia, & Kantarchi, 2011; Lee, Wang, & Noh, 2010). The overhear and suppression algorithm is commonly used to handle this issue in opportunistic routing algorithms. Unnecessary forwarding can be defined as the useless transmissions that occur during the forwarding process. Selecting the node that has less depth than the sender in transmission range is commonly used for handling the problem of reducing the number of transmission and the number of nodes that are selected to forward the data packet (M. Ghoreyshi, Shahrabi, & Boutaleb, 2016). The main disadvantage of this approach is that it solely defends on the distance between sender and receiver node without taking different matric into account. In location-based routing, the sending area has been layered and the shortest path is chosen on location information that is provided by GPS, shapes and link quality (Daeyoup Hwang et al., 2008). Moreover, selecting the efficient shortest path is one of the main problem in location free. This is due to lack of GPS information to shrink the transmission area. Lack of efficient shortest path selection which leads to network lifetime reduction and consumption of high amounts of energy is seriously affected by Opportunistic pressure based algorithm (Abdul Wahid, Lee, & Kim, 2014; Yan et al., 2008). Among the existing opportunistic pressure-based routing Depth Based Routing (Yan et al., 2008) employs poor shortest algorithm for handling the problem of nodes reduction and constraints, which is not efficient due to the use of depth information only. And this leads to high energy consumption. Hydrocast (Lee et al., 2010) and Void Aware Pressure Routing(VAPR) (Noh et al., 2012) employ modifying forwarding set reduction by ranking the neighbor nodes using 2-hop neighboring based on physical distance within transmission range. The main drawback of this scheme is that it required costly 2-hop neighboring nodes distance information. As a result, enhancing the overhear and suppression algorithm in pressure-based routing algorithms without the use of location information and topology information is essential to reduce the unnecessary network traffic due to duplicate packet forwarding and reduce the energy consumption.

1.2.1.3 Communication Void Handling Technique

While forwarding packet, if there is no qualified node with positive advancement to the sink it will drop. This is despite valid path from the sender node to the sink, and is called communication void (Ghoreyshi et al., 2017a). In TWSN greedy routing protocol has attained its peak in terms of void handling. But because of unique nature of UWSNs those protocols can never be applied directly. This really calls for developing effective void handling technique for UWSNs to enhance the routing. There are many routing protocols developed in recent years to tackle the problem of void. Some of which dealt with the situation and some of them can detect and avoid void. Communication void area is 3D area in UWSNs which is empty of nodes inside. This type of area prevents communication among network's members (Ghoreyshi et al., 2017a). Communication void is a key issue in opportunistic hop-by-hop routing that needs given serious attention. The technique of handling void is technical challenge. As matter of fact every opportunistic routing protocol is made up of packet forwarding and void handling mode (Kheirabadi & Mohamad, 2013). Looking for location information in UWASNs is very costly. This is because GPS is not applicable in underwater. Therefore, routine protocol is divided into location based and location free or depth-based (Kheirabadi & Mohamad, 2013). In geographical based or location-based nodes know their location information and identify their geographical location towards the destination while the other does not have the location information. Depth of nodes and dynamic address of nodes are used for identifying the positive progress area toward the destination. In depth-based routine there is likelihood of packet to involve in void or trapped nodes which leads to the dropping of the packet. Therefore, an efficient routing ought to have detect the void and or the trapped nodes and avoid them (Ghoreyshi et al., 2017a). Therefore, developing efficient void detection and avoidance algorithms without the use of location information and topology information still is required to increase the packet delivery ratio, especially in sparse networks.

1.3 Problem Statement

In UWSNs, sensor nodes spend main part of their limited energy to transmit the data packets. The process of designing and implementing a routing protocol for UWSNs faces serious difficulties that cannot be ignored such as high bit error rate, the long propagation delay, low bandwidth, and energy limitation due hash underwater environment (Ayaz et al., 2011; Kheirabadi, 2015; Kheirabadi & Mohamad, 2013; Lee et al., 2010). Thus, several energies efficient pressure-based opportunistic routing algorithms have been introduced to reduce the energy consumption while provide satisfactory packet delivery ratio. Each of these algorithms has its own advantages and disadvantages. Therefore, this study takes into account these challenges to design an efficient routing protocol in UWSN.

In pressure-based routing protocols, it is critical to select the next forwarding nodes. Few studies addressed the problem of selecting the next forwarding nodes (Darehshoorzadeh & Boukerche, 2015; Lee et al., 2010; Yan et al., 2008). Moreover, the use of inefficient forwarding node selection has direct effect on energy consumption and packet delivery ratio. Multi-metrics was not given attention in selecting forwarding nodes by the existing pressure-based routing protocols, which leads to high energy consumption and low packet delivery ratio. The use of residual energy metric reduces the total energy consumption. On the hand, the use of poor link quality in the process of transmitting the data packets leads to increase in data packet loss, which gives rise to low packet delivery ratio and high energy consumption (Diamant et al., 2016). Therefore, the use of link quality metrics has significant impact on reducing the energy consumption and improve the packet delivery ratio. Consequently, it is essential to design and develop an energy efficient algorithm that can be used to select the next forwarding nodes based on multi-metrics.

Despite the fact that overhear and suppression algorithm cannot efficiently suppress duplicate packet forwarding in opportunistic routing algorithms, the existing pressure-based routing algorithms have paid less attention to this issue (Lee et al., 2010). Taking care of this issue results in lower network traffic and lower energy consumption. However, the existing solutions use location information to control the size of advancement area and improve the efficiency of overhear and suppression algorithm, while finding this information leads to wasting the energy of nodes. Thus, it is necessary to design and develop a new algorithm to improve the efficiency of overhear and suppression algorithm without the use of location information and topology information in order to reduce unnecessary network traffic and decrease the total energy consumption.

Underwater nodes spend most part of their energy to transmit the data packets. A communication void tends to come into existence because of undefined deployment, navigation of ship, circuit issues, energy consumption, and mobility(Kanthimathi & Dejey, 2017). In routing, voids are areas packets failed to have progress forwarding, or the nodes are completely unavailable. This void divides the network causing packet loss, and congestion (Kanthimathi & Dejey, 2017). Thus, several communication void handling technique pressure-based routing algorithms have been introduced to eliminate void and provide satisfactory packet delivery. Each of these algorithms has its own merit and demerit (Kheirabadi, 2015). For these reasons, it is essential to introduce a novel void avoidance algorithm that can detect the void nodes without the use of location information and topology information and avoid these nodes in packet forwarding process to improve the packet delivery ratio, especially in sparse networks.

1.4 Research Goal

The key objective of this research is to propose a pressure-based routing protocol for UWSNs to deal with three main issues: to select the best forwarding nodes, suppress the duplicate packet forwarding and detect and avoid communication voids.

1.5 Research Questions

The general research question addressed in this study is:

How to design and develop an energy efficient pressure-based opportunistic routing protocol for UWSNs without the use of full location information and topology information to reduce the energy consumption and, at the same time, provide the satisfactory packet delivery ratio?

To answer this question, three sub research questions are provided as follows:

i) How to select the best forwarding nodes so as to reduce energy consumption and improve packet delivery ratio?

ii) How to suppress duplicate packet forwarding in order to decrease the unnecessary network traffic?

iii) How to design an energy efficient void detection and avoidance protocol without using full location information and network topology information to tackle communication voids in 3D UWSNs?

a) How to identify void node and trapped nodes without the use of full location information and network topology information?

b) How to select the forwarding set to avoid the void nodes in packet forwarding process?

1.6 Research Objectives

In order to achieve the research goal, several research objectives have been identified as follows:

i. To design and develop a reliable algorithm that will select the best forwarding nodes so as to reduce energy consumption and improve packet delivery ratio.

ii. To design and develop an algorithm that will suppress duplicate packet forwarding so as to decrease the unnecessary network traffic and reduce the total energy consumption.

iii. To design and develop energy efficient pressure-based routing algorithm that identifies the void and trap nodes and prevents these nodes in packet forwarding process to reduce packet loss and improve the packet delivery ratio especially in sparse networks.

1.7 Research Scope

The following constraints are given serious concern in this research.

i) Acoustic obstacles such as fishes, which alter the transmitted acoustic signal, are not considered.
ii) Source nodes in this research apply a Constant Bit Rate (CBR) traffic generation.
iii) Underwater nodes send private information and data packets to other underwater nodes in a friendly environment without any security issue between nodes.
iv) All underwater nodes are similar in terms of sensing, communication range, initial energy, memory size, and energy consumption in transmission and receiving per bit.
v) Salinity, temperature, and depth are insignificant on sound speed underwater environment, therefore, the effects of these parameters on sound speed are overlooked in this research.
vi) The performance of the proposed algorithms are evaluated and validated by AquaSim that is an independent package for supporting UWSNs in NS 2.

1.8 Research Contribution

In Emergency Evacuation and Recovery, the proposed routing protocol will help overcome the challenges face by opportunistically selecting the best available links/nodes to communicate with the rescue and emergency personnel and provides with help of dynamic selection more resilient search and rescue operations. Mine sites underwater are characterized by high signal attenuation and frequent network disruptions, the proposed routing allows field workers to always connect to the best communication unit in their surrounding and have their calls/traffic reliably transferred to the corresponding central safety unit in shortest minimum time and with less energy consumption. Other areas that this study can be applied are monitoring the marine

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