Ad Hoc Networks 11 (2013) 1603–1609

Contents lists available at SciVerse ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

A network coding based protocol for reliable data transfer in underwater acoustic sensor

Shaobin Cai [a,*], Zhenguo Gao [b], DeSen Yang [c], Nianmin Yao [a]

[a] Computer Science Dept., Harbin Engineering University, Harbin 150001, China
[b] Automation Dept., Harbin Engineering University, Harbin 150001, China
[c] Underwater Acoustic Engineering Dept., Harbin Engineering University, Harbin 150001, China

ARTICLE INFO

Article history:
Received 9 March 2012
Received in revised form 25 December 2012
Accepted 11 February 2013
Available online 27 February 2013

Keywords:
Underwater acoustic sensor network
Transport protocol
Reliability
Multiple paths
Network coding

ABSTRACT

VBF-NC (Vector Based Forwarding-Network Coding) is a reliable transport protocol for UWASNs (Underwater Acoustic Sensor Networks). It transfers packets, coded by network coding, over relay node sets, which are established by VBF (Vector Based Forwarding) routing protocol. However, only the error correction function of network coding is used by VBF-NC, the most important inbeing of network coding, which cannot only improve the throughput of network but also reduce transmission overhead, is not used by VBF-NC. So, in this paper, a network coding based protocol, called Multiple Paths and Network Coding (MPNC), is proposed. In MPNC, three disjoint paths are established firstly, and then, two groups of packets A and B, coded by network coding, are transmitted over the two side paths individually, and another group of packets C ($C = A \oplus B$) are transmitted over the middle path. The results of mathematical analysis and simulations show that, compared with VBF-NC, MPNC not only improve the throughput of network but also has a higher data delivery ratio and lower energy consumption without reducing the data transmission reliability.

1. Introduction

UWASN (UnderWater Acoustic Sensor Network) is a special kind of WSN (Wireless Sensor Network), which is consisted of underwater acoustic sensor nodes. The UWASN can be deployed for real-time warship monitoring, oceanographic data collection, environmental monitoring, and disaster prevention, etc. Hence, lots of researches have been done on it [1–3].

The design of a reliable data transfer protocol for UWASN is challenging due to the specific characteristics of acoustic channels: high bit error rates, high energy consumption, limited available bandwidth, low transmission speed, and long and unstable packet delivery delay. Traditionally, the data transmission reliability is improved by acknowledgements and/or FEC (Forward Error Correction). However, the data transmission protocols based on traditional acknowledgements, for example ARQ, are not suitable for UWASN [4–6]. Therefore, some improved ARQ-based protocols [6–9] have been proposed for UWASN. In some of these protocols, implicit acknowledgments are used to reduce the usage of explicit acknowledgments. Furthermore, some protocols [10–14], such as Segmented Data Reliable Transport (SDRT) [12,13], Network Coding in Rateless Fashion (NCRF) [14], and Network Coding with Implicit Acknowledgement (NCIA) [14], based on both FEC and acknowledgments are proposed to reduce the usage of acknowledgments further. However, the acknowledgements are still used by all above protocols. Therefore, some protocols only based on FEC are proposed. ADaptive rELIable traNsport (ADELIN) [15,16] applies Bose, Ray-Chaudhuri, Hocquenghem (BCH) coding and/or Erasure Codes (EC, a simple variant of Tornado Codes) coding to guarantee the data transfer reliability according to the distance between two forwarding nodes without any

* Corresponding author. Tel.: +86 451 82519610.
E-mail address: caishaobin@hrbeu.edu.cn (S. Cai).

1570-8705/$ - see front matter
http://dx.doi.org/10.1016/j.adhoc.2013.02.001

acknowledgements. Based on Vector Based Forwarding (VBF) routing protocol [17], Vector Based Forwarding-Network Coding (VBF-NC) [18] is proposed, it transmits packets coded by network coding over relay node sets to improve the data transfer reliability without any ACKs.

In VBF-NC, only the error correction function of network coding is used, the most important inbeing of network coding, which not only can improve the throughput of network but also can reduce the transmission overhead, is not used by VBF-NC. So, in this paper, a network coding based protocol, called Multiple Paths and Network Coding (MPNC), is proposed not only to improve the throughput of network but also to reduce transmission overhead. In MPNC, three disjoint paths are established firstly, and then, two groups of packets A and B, coded by network coding, are transmitted over the two side paths, and another group of packets C ($C = A \oplus B$) are transmitted over the middle path. The rest of the paper is arranged as following: firstly, the related works are introduced in Section 2; secondly, MPNC is proposed in Section 3; thirdly, the performances of MPNC are analyzed via mathematics and simulations in Section 4; finally, a conclusion is drawn in Section 5.

2. Related works

There are some protocols, proposed for data transmission reliability in UWASN. Normally, these existed protocols can be cataloged into 3 classes: (1) protocols based on acknowledgments; (2) protocols based on FEC; (3) protocols based on both acknowledgments and FEC.

2.1. Protocols based on acknowledgments

ARQ (Automatic Repeat-reQuest) is the most basic reliable data transfer protocol based on acknowledgments. However, in a densely deployed UWASN, the ARQ packets are overheard by all neighbors of a sender. So, lots of energy is waste. Furthermore, if ARQ packets lose during their transmission, the limited energy and bandwidth are wasted to retransmit the already received data packets. Hence, some improved ARQ protocols are proposed.

In [4], a sender sends packets with fixed gap, and determines the retransmission of a packet by the acknowledgement received after its having sent other n packets. In [5], a receiver requests the retransmission of a data packet from a neighbor of the sender instead of the sender. In [6–9], the relayed packets of downstream nodes are looked as implicit acknowledgements for the sent data packets.

Compared with the traditional ARQ protocols, these improved ARQ protocols have shorter data delivery delay and lower power consumption. However, in these protocols, sender has to determine whether to retransmit packet or not by its received implicit or explicit acknowledgement. So, the date delivery delay of these protocols is still long.

2.2. Protocols based on acknowledgement and FEC

In order to reduce the date delivery delay, FEC (Forward Error Correct) is used by some protocols to reduce the usage of acknowledgements. In RTS (Reliable Transport and Storage) [10], Fountain Coding is used; in [11], the combination of Tornado and LT (Luby Transform) is used. In SDRT (Segmented Data Reliable Transport) [12,13], the EC code is used; in NCRF (Network Coding in Rate-less Fashion) protocol [14] and NCIA [14], network coding is used. So, in the above protocols, only a few ARQs are used to inform sender the successful reception of data packets. However, if their explicit ARQs lose during their transmissions, then the sender has to constantly send the already received data packets. And, lots of limited energy and bandwidth are wasted.

2.3. Protocols based on FEC

In order to reduce the data delivery delay further, some protocols, only based on FEC, are proposed. ADELIN (ADaptive rELIable traNsport) is a completely non-feedback reliable data transfer protocol for UWASN [15,16]. BCH (Bose, Ray-Chaudhuri, and Hocquenghem) or/and ECs (Erasure Codes) are used in this protocol according to the BER (Bit Error Ratio) of a channel, which is determined by the distance between nodes when optimal frequency is used for communication [19]. In its cooperative scenario (Fig. 1), the nodes, for example R, etc., are defined as redundant nodes, and they relay their received data packet to increase the reliability of data packet transmission.

On the basis of ADELIN Protocol, IPool-ADELIN protocol [20] is proposed to improve ADELIN. In IPool-ADELIN, only parts of redundant nodes are defined as IPool node (Fig. 2). For example, in Fig. 2, R is defined as IPool node for upstream S and downstream node D. Node R overhears the data packet relays of both upstream node S and downstream node D, and looks its overheard data packets from

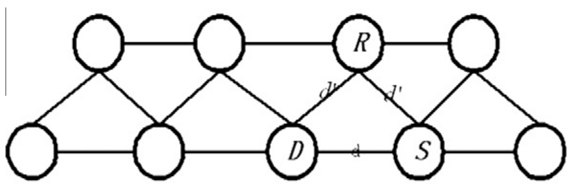


Fig. 1. An example of cooperative scenario.

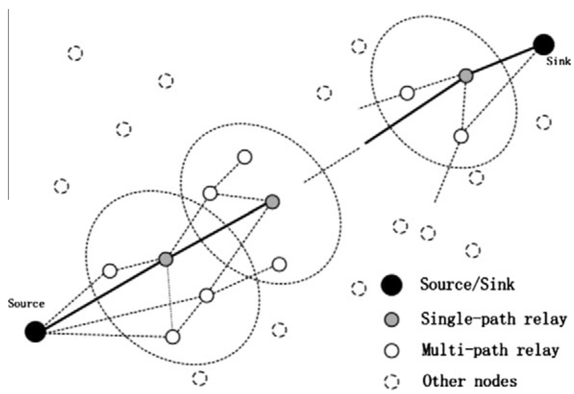


Fig. 2. An example of VBF-NC [18].

D as the implicit acknowledgements of the data packets from S. On the base of overhearing and buffering, R only relay some data packets from S, which has not been implicitly acknowledged by the packets from D. by the method, IPool-ADELIN can guarantee the data packet transmission reliability as high as ADELIN at much lower cost of data transmission overhead.

On the basis of VBF [17] route protocol, VBF-NC is proposed for data transmission reliability for UWASN [18]. In this protocol, a route vector is established by VBF protocol firstly; secondly, the nodes around the route vector are defined as members of forwarding node sets; thirdly, the packets coded by network coding are relayed by the nodes of forwarding sets (Fig. 2). So, in VBF-NC, the more forwarding nodes are defined, the more coded packets are relayed, the higher reliability is acquired at the cost of higher overhead. In order to balance the reliability and overhead, the number of relayed packets must be adjusted by tuning either the sending energy of nodes or the number of redundant data packets of coding [18].

Compared with the protocols based on retransmission, the protocols based on FEC do not wait for acknowledgements. Therefore, their data packets can be transferred in pipelining, and the delivery delay and energy consumption of data packet transmission can be reduced greatly.

3. MPNC

By network coding and forwarding node sets, VBF-NC can acquire a high successful delivery ratio. However, in VBF-NC, all coded packets are transmitted by all nodes of forwarding node sets, and its transmission overhead is high. Another most important character of network coding, which can improve the throughput of network and reduce transmission overhead, is not made full use of. Hence, in this paper, a protocol based on Multiple Paths and Network Coding, MPNC (Multiple Paths and Network Coding), is proposed.

Network coding technology [21] was proposed on IEEE information science proceeding by R. Ahlswede of Chinese University of HongKong in 2000. Lee proved that the multicast capacity of network can be reached by using linear network coding [22].

Butterfly (Fig. 3) is a typical example of network coding to reach the maximum multicast capacity of network. In Fig. 3a, the flow capacity from node S to node Y or Z can reaches 2. However, both of them share the link (W,X), whose bandwidth is 1. So, if node W and X only relay their received packet, then the receiving rates of node Y and Z cannot reach to 2 at the same time. If node W and X codes the data by network coding, then the receiving rates of node Y and Z can reach 2 at the same time (Fig. 3b). Hence, network coding has great advantage in wireless transmission.

In our previous study [20], IPool node overhears and buffers packets from its upstream node and downstream node, and relays the packets, which are only received from upstream node to guarantee the transmission reliability and reduce transmission cost. The character is also introduced into MPNC. In MPNC, on the three disjoint paths, two groups of coded packets A and B are transmitted over the two side paths, another group of packets C ($C = A \oplus B$) are transmitted over the middle path sequence. Therefore, in MPNC, any two nodes of a level can work as an IPool node to correct forwarding error of the third node of the same level by their buffered and relayed packets.

Fig. 4 describes how MPNC works after three disjoint paths being established. In Fig. 4, there are three disjoint paths A, B and C, and two groups of K original packets O_A and O_B will be transmitted over the paths. The number $(1,2,\ldots,3n+3)$ represents sequence number of circles, at which the nodes send out coded packets. The working flow of MPNC is described as following:

(1) Node S encodes O_A and O_B by network coding individually to acquire two packet groups A and B, each of which has $K + K_1$ coded packets. And then, node S encodes another packet group C, which is consisted of c_i (c_i=$a_i \oplus b_i$, $i = 1,\ldots,K + K_1$).

(2) At circle 0, node S sends out packets of group A; at circle 1, node S sends out packets of group B; at circle 2, node S send out packets of group C.

(3) Although node A_1 can receive lots of packets of group A, its received packets are not enough for decoding most time because of the high bit error ratio of acoustic channel.By $a_i = b_i \oplus c_i$ ($i = 1,\ldots,K + K_1$), node A_1 can acquire some un-received packets of group A from its received packets of group B and C. And then, it can decode the packets of group A to acquire the K original packets of O_A.

(4) After recoding the K original packets of O_A by network coding, node A_1 sends out the packets of group A at circle 3.

(5) Although node B_1 can receive lots of packets of group B, its received packets are not enough for decoding most time because of the high bit error ratio of acoustic channel.By $b_i = a_i \oplus c_i$ ($i = 1,\ldots,K + K_1$), node B_1 can acquire some un-received packets of group B from its received packets of group A and C. And then, it can decode the packets of group B to acquire the K original packets of O_B.

(6) After recoding the K original packets of O_B by network coding, node B_1 sends out the packets of group B at circle 4.

(7) The packets of group C are consisted of $c_i = a_i \oplus b_i$, $i = 1,\ldots,K + K_1$. Group C does not have itself redundancy packets. So, in order to acquire all packets of group C, node C_1 has to acquire the original packets of group O_A and O_B. By $b_i = a_i \oplus c_i$ and $a_i = b_i \oplus c_i$ ($i = 1,\ldots,K + K_1$), node C_1 firstly acquires some un-received packets of group A and B. And then, it acquires the original packets of group O_A and O_B by its received and acquired packets of group A, B and C.

(8) After recoding by network coding, Node C acquires packets of group A, B and C, and sends out all packets of group C at circle 5.

(9) Similarly, the coded packets are transmitted by the nodes A_i,B_i and C_i over the network.

(10) Sink node E receives and decodes his received packets to acquire original data packets of group O_A and O_B.

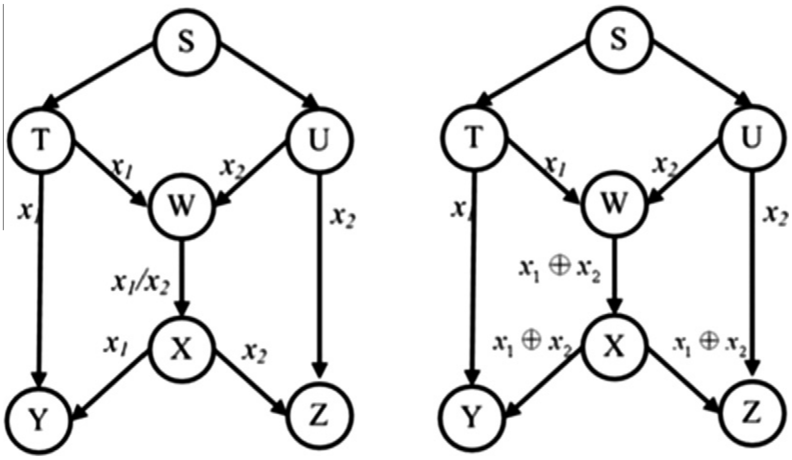


Fig. 3. Butterfly diagram.

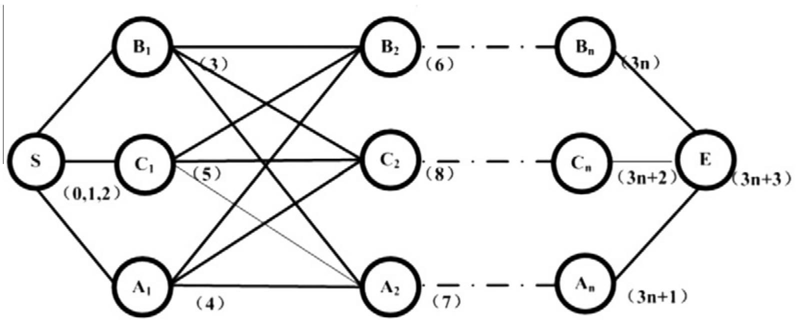


Fig. 4. MPNC work flow.

In VBF-NC, one group of coded packets are relayed by forwarding nodes of forwarding sets, each of which has at least two nodes; in MPNC, two groups of data packets can be transmitted over three disjoint paths reliability. So, when two groups of packets are needed to transformed, MPNC needs about $3(n+1)$ node relays; VBF-NC needs at least $2 \times 2(n+1) = 4(n+1)$ node relays. So, compared with VBF-NC, MPNC not only reduces the overhead of packets transmission but also improving the output of network without reducing its reliability of transmission. So, the energy consumptions of data transmission are reduced greatly, and the lifetime of network is prolonged.

4. Analysis

In this section, the performance of MPNC is analyzed in a 9-hop UWASN, and experiments are done 1000 times in each scenario to acquire average value as results. The BER of channel is direct ratio to the distance between nodes when the optimal frequency is used for communication [15]. So, the BER is between 10^{-4} and 1.5×10^{-4} when the distance among nodes is between 1 km and 41.5 km in the following experiments. The successful delivery ratio and the normalized energy consumption are used here to describe the performance of protocol. The normalized energy consumption is defined as following [18]:

$$T = \frac{\sum_{i=1}^{H} H_i}{R}$$

In the above formula, R presents the successful delivery ratio; T_i presents the average number of received packets of a relay group from its upstream relay group.

Furthermore, according to the environment settings [18], the simulation environment of MATLAB and Aquasim [23] are defined.

4.1. Analysis by MATLAB

The performance of the protocols is firstly analyzed by MATLAB in this sub-section. Fig. 5 describes the relationship between the node distance and the successful delivery ratio when different types of coding are used. In Fig. 5, $n + n$ presents a coded packet group, which is consisted of n original packets and n redundancy packets. The successful delivery ratios of three types of coding are almost 100% when the distance among node is not more than 37.5 km. The 15 + 15 and 30 + 30 coding type is till high enough even when the distance among node is about 40 km. So, the protocol is strong enough even when the distance between nodes is more than 40 km.

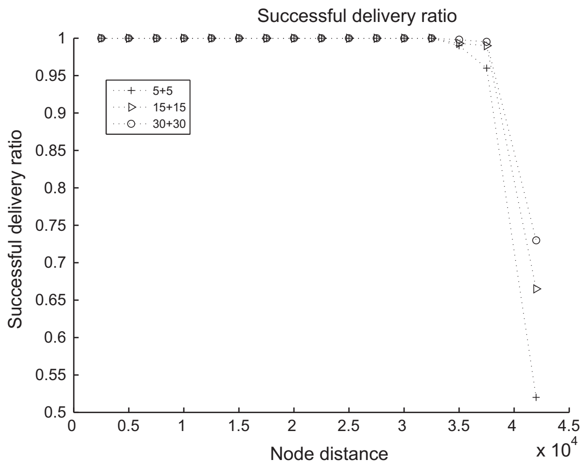


Fig. 5. The relationship between successful delivery ratio and node distance with different coding type.

Fig. 6 describes the relationship between the node distance and normalized energy consumption when different types of coding are used. The normalized energy consumptions of three coding types are almost identical when the distance among node is no more than 37.5 km. when the distance among node is larger than 37.5 km, the 5 + 5 coding type is the weakest, its normalized energy consumption increases fastest because it loses most packets during data transmissions; the 15 + 15 coding type is weaker, its normalized energy consumption increases faster because it loses more packets during data transmissions; the 30 + 30 coding type is the strongest, its normalized energy consumption increases slowest because it loses the least packets during data transmissions.

From the picture 5 and 6, it can be seen that 5 + 5 is strong enough most time. In order to reduce normalized energy consumption, $K = 15$ is defined here, and K is defined according to the distance between nodes as following to find a suitable value of K:

(1) $K = 0$, when $d < 10$ km;
(2) $K = 5$, when 10 km $\leqslant d < 30$ km;
(3) $K = 10$, when 30 km $\leqslant d < 35$ km;
(4) $K = 15$, when 35 km $\leqslant d < 32.5$ km;
(5) $K = 18$, when 32.5 km $\leqslant d < 41.5$ km.

Figs. 7 and 8 individually describes the relationship between the successful delivery ratio, normalized energy consumption and the node distance of protocols. In these figures, Ana presents the mathematical results; Sim presents the simulation results of MATLAB. From Figs. 7 and 8, it can be seen that, when the distance between nodes is less than 37.5 km, the successful delivery ratios of two protocols are similar. However, MPNC has lower normalized energy consumption. When the distance between nodes is larger than 37.5 km, in order to maintain higher successful delivery ratio, MPNC increases the value of K, and the normalized energy consumption increases. In both

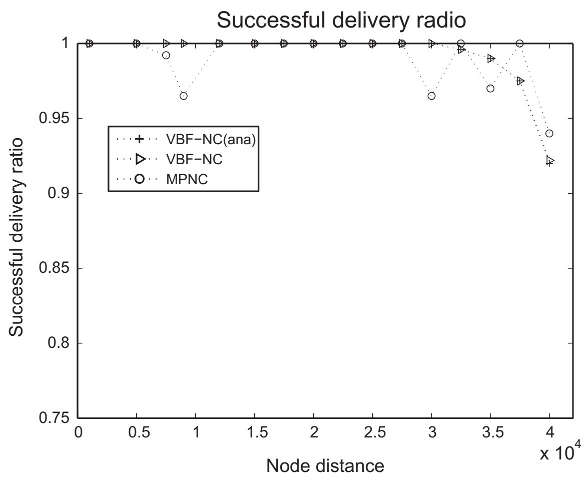


Fig. 7. The relationship between successful delivery ratio and node distance of protocols.

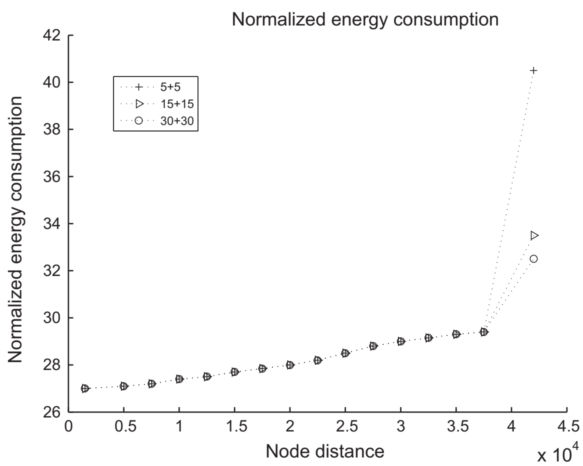


Fig. 6. The relationship between normalized energy consumptions and node distance with different coding type.

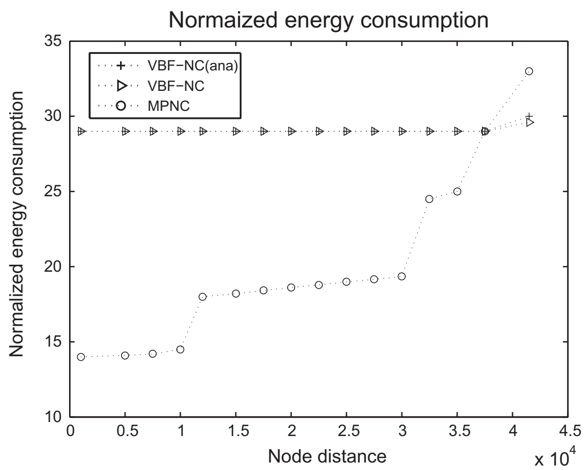


Fig. 8. The relationship between normalized energy consumption and node distance of protocols.

Figs. 7 and 8, the value of successful delivery ratios and normalized energy consumption do not change smoothly just because the value of K does not change smoothly.

In Fig. 7, there are some zones, in which the successful delivery ratios of MPNC are lower than 100% because of its smaller K. However, with the increase of K, the data delivery ratios increase up to 100% again. So, according to the results of Fig. 6, the successful delivery ratio can reach 100% when the K is adjusted as following:

(1) $K = 0$, when $d < 5$ km;
(2) $K = 5$, when 5 km $\leqslant d < 27.5$ km;
(3) $K = 10$, when 27.5 km $\leqslant d < 32.5$ km;
(4) $K = 15$, when 32.5 km $\leqslant d < 37.5$ km;
(5) $K = 18$, when 37.5 km $\leqslant d < 41.5$ km.

From Fig. 8, it can be seen that, even when $K = 15$, the normalized energy consumption of MPNC is much lower than that of VBF-NC. So, compared with VBF-NC, by dynamically adjusting its coding redundancy according to the distance between nodes, MPNC can acquire a higher successful delivery ratio at lower normalized energy consumption.

4.2. Analysis by Aqua-Sim

In order to approve the analysis results of MATLAB above, the performance of the protocols is analyzed by Aqua-sim [23] in this sub-section furthermore. In this sub-section, in order to show the influence of K on the successful delivery ratio, and compare the performance with the mathematical analysis results, the K is also defined as old one, not as the adjusted one in the following experiments.

Figs. 9 and 10 individually compare the analysis results of both MPNC and VBF-NC. When the distance between nodes is small, fewer abundant packets is used by MPNC, the successful delivery ratio of MPNC is a little lower than that of VBF-NC sometimes, and the normalized energy consumption of MPNC is much lower than that of VBF-NC.

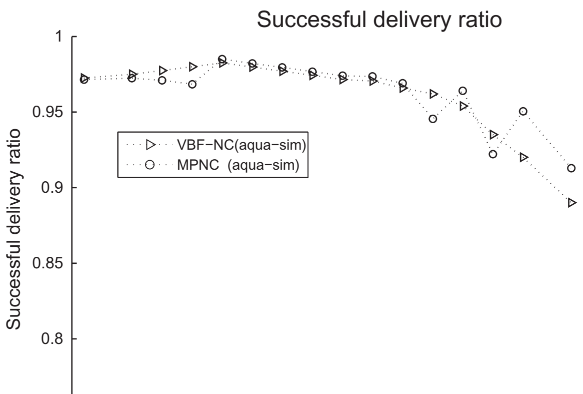


Fig. 9. The relationship between successful delivery ratio and node distance of VBF-NC and MPNC.

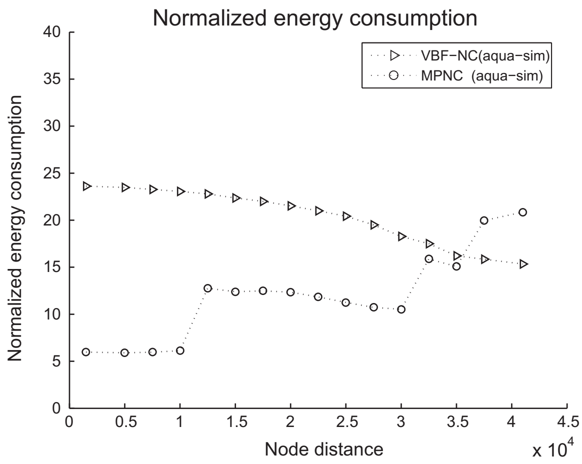


Fig. 10. The relationship between normalized energy consumption and node distance of protocols of VBF-NC and MPNC.

With the increasing of the distance between nodes, more and more abundant packets are added by MPNC to maintain its successful delivery ratio, and its normalized energy consumption increases with the increase of the abundant packets. When the distance between nodes is larger than 37.5 km, the delivery ratio of MPNC is a much higher than that of VBF-NC at the cost of higher normalized energy consumption. Although the simulation results show that the successful delivery ratio of MPNC is a little lower than that of VBF-NC sometimes, MPNC can acquire higher successful delivery ratio by adjusting K. From the mathematical results of Fig. 6, it can be seen that the normalized energy consumption of MPNC is much lower than that of VBF-NC most time even when the adjusted K is used. So, the performance of MPNC is better than that of VBF-NC as a whole.

5. Conclusion

On the basis of analyzing the existed reliable data transfer protocols for UWASN, MPNC is proposed. In, MPNC, three disjoint paths are established, and then, two groups of packets A and B, which are individually coded by network coding, are transmitted over two side paths, and another group of packets, $A \oplus B$, are transmitted over the middle path. Hence, two groups of packets can be transmitted over three paths reliably. The simulation results show that, compared with VBF-NC, MPNC acquires much lower energy consumption with the similar reliability of data transmission.

Acknowledgements

The paper is supported by National Science foundation of China (41176082, 61073182, 61073183), the Fundamental Research Funds for the Central Universities (HEUCF1006), and Young backbone teacher project of Heilongjiang province (1155G15).

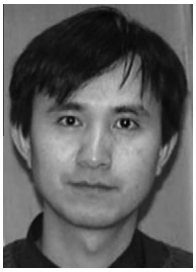
References

[1] http://www.seaweb.org/.
[2] http://www.onr.navy.mil/sci_tech/ocean/reports/docs/nopp_funded/01/bcbodonn.pdf.
[3] http://www.princeton.edu/dcsl/aosn/.
[4] Mingsheng Gao, Wee-Seng Soh, Meixia Tao, A transmission protocol for continuous ARQ protocols over underwater acoustic channels, ICC09 (2009) 1–5.
[5] Jae Won Lee, Jin Yong Cheon, Ho-Shin Cho, A cooperative ARQ scheme in underwater acoustic sensor networks, OCEANS'10 (2010) 1–5.
[6] Hwee-Pink Tan, Winston K.G. Seah, Linda Doyle, A multi-hop ARQ protocol for underwater acoustic networks, OCEANS07 (2007) 1–6.
[7] Valera Alvin, Pius W.Q. Lee, Hwee-Pink Tan, Huiguang Liang, Winston K.G. Seah, Implementation and evaluation of multihop ARQ for reliable communications in underwater acoustic networks, OCEANS '09 (2009) 1–6.
[8] Jae-Won Lee, Jong-Pil Kim, Ji-Hye Lee, Jang Youn Seon, Kyeong Cheo Dho, Kweon Son, Ho-Shin Cho, An improved ARQ scheme in underwater acoustic sensor networks, OCEANS'08 (2008) 414–432.
[9] Haojie Zhuang, HweePink Tan, Valera Alvin, Zijian Bai, Opportunistic ARQ with bidirectional overhearing for reliable multihop underwater networking, Oceans 10 (2010) 1–6.
[10] Rui Cao, Liuqing Yang, Reliable transport and storage protocol with fountain codes for underwater acoustic sensor networks, WUWNet '10 (2010) 18–21.
[11] Guangpeng Lv, Zhongwen Guo, Haipeng Qu, Zhaodong Che, Study of RFEC-based transport protocol in underwater acoustic sensor networks, WiCOM08 (2008) 1–4.
[12] Peng Xie, JunHong Cui, An fec-based reliable data transport protocol for underwater sensor networks, Computer Communications and Networks (2007) 747–753.
[13] Peng Xie, Zhong Zhou, Zheng Peng, Jun-Hong. Cui, Zhijie Shi, SDRT: A reliable data transport protocol for underwater sensor networks, Ad Hoc Networks 8 (7) (2010) 708–722.
[14] Daniel E. Lucani, Muriel Mdard, Milica Stojanovic, Network coding protocols for underwater networks: the benefits of implicit acknowledgement, WuWNet '07 (2007) 25–32.
[15] Bin Liu, Florent Garcin, Fengyuan Ren, Chuang Lin, A study of forward error correction protocols for reliable transport in underwater sensor networks, SECON08 (2008) 197–205.
[16] Bin Liu, Hongyang Chen, Xianfu Lei, Fengyuan Ren, Kaoru Sezaki, Internode distance-based redundancy reliable transport in underwater sensor networks, EURASIP Journal on Wireless Communications and Networking (2010) 1–16.
[17] Peng Xie, JunHong Cui, Li Lao, VBF: vector-based forwarding protocol for underwater sensor networks, IFIP-TC6 Networks (LNCS3976) (2006) 1216–1221.
[18] Zheng Guo, Bing Wang, Peng Xie, Wei Zeng, JunHong Cui, Efficient error recovery with network coding in underwater sensor networks, Ad Hoc Networks. 7 (4) (2009) 791–802.
[19] Bin Liu, Hao Wen, Fengyuan Ren, Chuang Lin, Performance analysis of reliable transport protocols joint with the optimal frequency and optimal packet length in underwater sensor networks, WoWMoM2008, 2008.
[20] Shaobin Cai, Zhenguo Gao, DeSen Yang, Jing Zhao, Yunlong Zhao, IPool-ADELIN: an extended ADELIN based on IPool node for reliable transport of underwater acoustic sensor networks, Ad Hoc Networks, Available online 28 April 2011.
[21] Rudolf Ahlswede, Ning Cai, ShuoYen Li, Raymond Wai-Ho Yeung, Network information flow, IEEE Transaction on Information Theory 46 (4) (2000) 1204–1216.
[22] S.Y. Li, R.W. Yeung, N. Cai, Linear network coding, IEEE Transaction on Information Theory 49 (2) (2003) 371–381.
[23] Aqua-Sim: An NS2 based Underwater Sensor Network Simulator, Underwater Sensor Network (UWSN) Lab, University of Connecticut. <http://uwsn.engr.uconn.edu/aquasim.tar.gz>.

Shaobin Cai, born in 1973. Ph.D., Professor of computer department, Harbin Engineering University. Post Doctor of computer department, UCLA, Member of China Computer Federation. His primary research interests include ad hoc networks, wireless sensor network, and underwater acoustic sensor network.

Zhenguo Gao, male, born in 1976. Ph.D., Professor of automation department, Harbin Engineering University. Member of China Computer Federation. His primary interests include ad hoc network, network coding and wireless sensor network.

Nianmin Yao born in 1974. Ph.D., Professor of computer department, Harbin Engineering University. Member of China Computer Federation. His primary research interests include wireless sensor network and network storage.



Deshen Yang, male, born in 1957. Professor of underwater acoustic engineering department, Harbin Engineering University. His primary interests include underwater acoustic channel, localization of underwater acoustic sensor network.