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

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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

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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

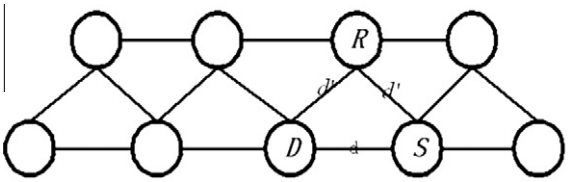

Fig. 1. An example of cooperative scenario.

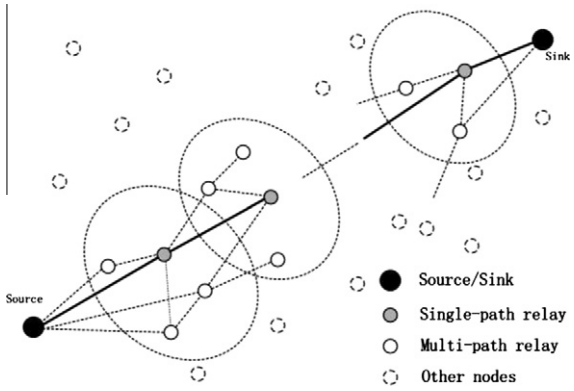

Fig. 2. An example of VBF-NC [18].