Assessing the performance of different TCP congestion mechanisms in underwater wireless sensor networks

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Abstract: Data transmission in Underwater Wireless Sensor Networks (UWSNs) is one of the key enablers used in technologies for future ocean-monitoring systems and other underwater applications. The use of acoustic waves in UWSNs suffer from a high propagation delay, as well as a limited available bandwidth due to the high-noise level, making the use of the different traditional existing protocols a major challenge in this environment. In this paper, we have chosen two TCP mechanisms already defined: TCP Vegas and TCP New Reno, to evaluate the effects of variable TCP packet size and TCP connection density in a subsea network under two common routing protocols, namely AODV and DSDV. The simulation results show that the performances of the two TCPs using DSDV routing protocol provide a more efficient result than those using the AODV routing protocol and that New Reno TCP gives better results than Vegas TCP in the UWSNs.

Keywords: underwater wireless sensor networks; TCP; TCP Vegas; TCP New Reno; AODV; DSDV.

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1 Introduction

Underwater Wireless Sensor Network (UWSN) is a network that consists of sensor nodes deployed in underwater environment to perform specific tasks such as monitoring physical phenomena in water and target detection. UWSNs admits a large set of applications that ranges from scientific, environmental, commercial to military applications. In an underwater environment, the exploration and improvement of ocean observing systems is done using a specific submarine support dedicated to obtaining and exchanging important information. The transmission of data is done using submarine wireless sensor networks (UWSN). The use of this type of network is fundamental in various fields of application, namely the control of pollution of oceans and rivers, as well as the forecast of natural disasters such as the tsunami. The oil industry also uses UWSNs (Mateen et al., 2019). In addition, the field of aquaculture relies mainly on submarine sensors for the monitoring of their aquatic fish farms. And it turns out that this field of application is one of the reasons that led us to conduct this study, since our country is bounded on the north by the Mediterranean Sea and on the west by the Atlantic Ocean which gives it a wide water surface throughout these two maritime coasts. This imposes the introduction of several submarine sensor networks for all possible applications.

UWSN brings new challenges that do not exist in terrestrial Wireless Sensor Networks (WSNs) because of the radical difference in terms of propagation in the acoustic environment or even in radio. With the recent development of the last decade in acoustic transmission techniques, data transmission in underwater environment is becoming a reality. Previous studies have suggested that the TCP protocol is inadequate for UWSN. The reason behind this, is that TCP depends on accurately measuring the Round-Trip Time (RTT) in order to appropriately adjust the congestion window. The long propagation delay of acoustic waves in water increases the RTT which adversely affects the TCP throughput. Furthermore, the high variability of the RTT makes it difficult to adjust the timeout value as the TCP congestion mechanism. It is difficult to distinguish between long propagation delays and missing acknowledgement. Furthermore, the TCP performance underwater is further reduced due the high error rates on the acoustic connections though; this phenomenon is also encountered in wireless radio networks (Cui et al., 2006).

Improving TCP performance in WSNs has been a focus of research activity for several years but research in underwater networks environment has not been deeply addressed. The characteristics of the underwater wireless network have a significant impact on TCP performance due to its differences from standard wireless networks and wired networks (Zhou et al., 2007). The use of acoustic waves gives a very long propagation time (Kularia et al., 2016), with a low bandwidth and a high probability of error and a specially limited energy with considerable packet losses due to what is error of privilege, resulting in delays of significant variations. These sudden delays violate most of TCP design assumptions.

In this paper, we study the behaviour of two variants of TCP (Vegas and New Reno) under two different routing protocol families widely deployed in UWSN, the first being derived from the proactive routing protocol family: Destination Sequenced Distance Vector (DSDV) and the second comes from the reactive routing protocol family: Ad hoc On-Demand Distance Vector (AODV).

In an ad hoc network, AODV being a reactive protocol it gives the mobile nodes an easy and quick adaptation to dynamic link disputes since it holds information from routes to active destinations only which allows mobile nodes to have accurate information in a short time (Perkins et al., 2003). The proactive routing protocol DSDV is suitable for routing ad-hoc networks from the conventional Routing Information Protocol (RIP). It is based on adding the sequence number as a new attribute in the RIP routing table, based on this new attribute the mobile nodes can prevent the formation of routing loops because they now know the last value of the route saved to those already outdated (Guoyou, 2002).

In order to better discover the effect of UWSNs on the behavior of TCP Vegas and TCP New Reno and to provide some guidelines that will service for performance tuning, we start by investigating the impact of Packet Size and the number of TCP connections performances over underwater environment using AODV and DSDV as routing protocols. The remainder of this article will be presented as following: Section 2 surveys some related work. Section 3 describes our system model analysis. Section 4 presents our experimental set up, simulation scenarios and gives the considered performance metrics. Section 5 provides detailed analysis of simulation results. Section 6 gives a general conclusion of our work and opens the suggestion for some future works.

2 Related work

There are a myriad available studies that are focusing on the performance of TCP in terrestrial WSNs. However, very few studies have tackled the counterpart problem in UWSNs. In this part, we shall present some previous works related to TCP performances using DSDV and AODV routing protocols in both UWSNs and in WSNs for the sake of completeness.

Several studies were set up to assess and improve the routing performance of AODV and DSDV protocols in WSNs in Chavan et al. (2016), Sharma and Kumar (2016) and Daas et al. (2015).The use of AODV is highly recommended for the transmission of high-video packets as it is proven in the comparative study in Chowdhury et al. (2004) with DSDV and OLSR another routing protocol for Optimised Link State Routing Protocol (Clausen and Jacquet, 2003), since it gives good performances in terms of bandwidth with low-packet jitter.

To address the challenges of information routing in UWSNs, different routing protocols have been proposed, and we can find many surveys that present different routing protocols for UWSNs in the literature (Khan et al., 2018; Li et al., 2016). Vector Based Forwarding (VBF) (Xie et al., 2006) is part of this underwater proposed protocols, (DBR) (Yan et al., 2008) is also a suitable routing protocol for this environment. In Zhang et al. (2013) presented LAFR routing protocol based in link state and feedback adaptive. Furthermore, to the work in Tariq et al. (2015) gives a new routing protocol called DREE based on reliable distance and energy efficiency. In addition of a new routing protocol proposed in Wahid et al. (2014) solved the problem of energy consumption in a reliable and efficient way. Javaid et al. (2015) described a new efficient data collection assisted and in Ali et al. (2014) layer-based flood routing protocol based on the layer angle is presented. Thus, decreasing the energy consumption of the network and increasing the data transfer rate with a short delay are the basic requirements for the proper functioning of different types of marine applications that all these proposed protocols must meet. Faheem et al. (2017), while different performance metrics for mobile ad hoc networks were considered and compared such as routing overhead, Packet Delivery Ratio, throughput and end to end delay (Xie et al., 2006; Yan et al., 2008; Zhang et al., 2013; Tariq et al., 2015; Wahid et al., 2014: Javaid et al., 2015; Ali et al., 2014).

Sawarkar and Saraswat (2016) presented us a performance analysis specific to each type of TCP, starting with TCP Tahoe, passing by TCP Reno, TCP New Reno (Henderson et al., 2012) and at the end TCP Vegas under congestion. In this paper, the authors resorted to NS-2 to simulate these four types of TCP and analyse the results in terms of throughput, packet drop rate, and latency. Different research studies tried to solve TCP congestion problems in MANET and were reported in the literature. For instance, Hamamreh and Bawatna (2014) presents the most varied TCP that could maintain a good end-to-end behaviour. Furthermore, the authors give a study analysis to adjust the value of the network size, define the mobility of the nodes with different conditions of the wireless channels in order to increase the performance of TCP over MANET. Another work concerning the performance of the Tahoe, Reno and New Reno TCP transmission control protocol was conducted by Matsuo et al. (2018) but to evaluate the performance of two WMN architectures of Wireless Mesh Networks the normal distribution and the uniform distribution, taking into account fairness index, throughput, delay and PDR metrics, they used ns-3 simulator to validate their simulations.

In aquatic communication several studies have proved that among essential characteristics in a long link is the data rate as well as a wide propagation delay, moreover all applications that are based on TCP their features severely degrade the end to end yield. To deal with this problem, a new Linear Coded Digraph Routing (LCDR) was presented by Chin-Ya, Parameswaran and Kewal in Huang et al. (2011), based on the multiple path routing solution combining this protocol with the local sequencing solutions it also uses the network coding principle and adapts a management mechanism for the detection of data duplication.

During congestion, a source node cannot restore its congestion window in a short time to return to its normal state which is negatively reflected on the return of TCP performance when RTT is too long (Jiang, 2018). Chughtai et al. (2017) trunked network with limited constraints, it is found that making the decision to detect congestion either at the node level or at the link level is extremely very critical and important. Jafari et al. (2018) mitigated and avoid congestion, the authors propose an efficient model to improve the functioning of TCP, and this model uses the segmentation in a way that its transmission of data is faster and to increase its throughput. The proposed mechanism is shown to improve the transmission mechanism of TCP in a considerable way.

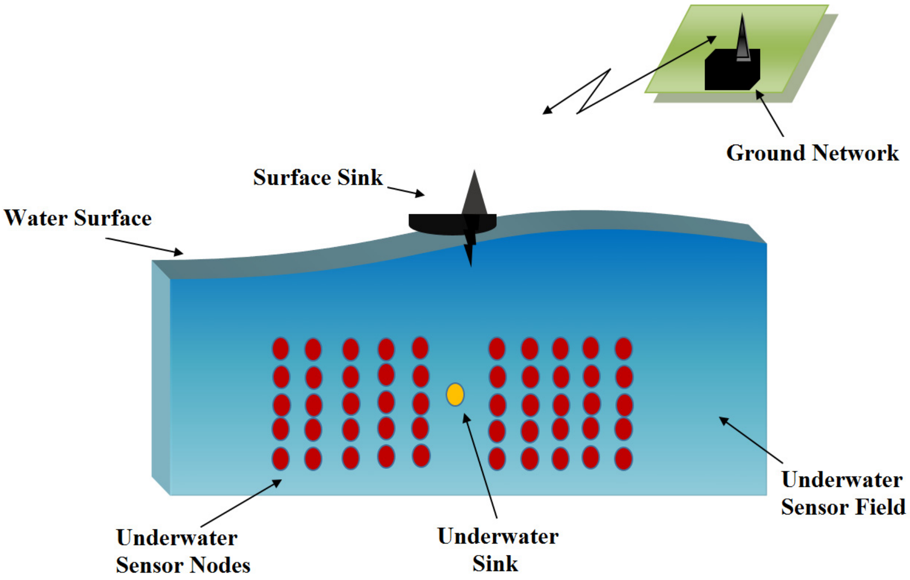
Albuquerque et al. (2001) studied the effect of TCP Packet Size in a congested link environment and correlated errors channel, they present the relationship of the ratio α with respect to round trip links in a network of a single TCP Reno connection. Albuquerque et al. support their study by performing extensive simulations using NS-2 Network Simulator.

3 System model analysis

3.1 Network model

In this section, we present our network model that will define the architecture of our UWSN as showed in Figure 1. Our network is composed by 100 underwater sensor nodes placed at the bottom of the sea, uniformly distributed in 2000 m by 2000 m squares.

Figure 1 Underwater wireless sensor architecture



To collect the transmitted data packets we have placed one submarine sink node in the middle of our network, with a distance of 84 m away from its nearest neighbour. The transmission range between sensor nodes varies between 75 m and 84 m. To adjust the sensor nodes in our marine network, all sensors are static and placed on a fixed common height, and the initial energy is 10 kJ for each node. To route data from sending nodes to sink node, AODV and DSDV were implemented as routing protocols then, BroadcastMac, UnderwaterPhy were respectively used for MAC layer protocol to access channel and physical layer.

3.2 TCP model analysis

In this work, we consider the performance of TCP Vegas and TCP New Reno in underwater environment under different settings for three main reasons. First, TCP Vegas is known to be a viable choice in UWSN due to its ability for fast reactivity when it comes to retransmitting a lost segment. Second, TCP Vegas is able to anticipate congestion, and to adjust its transmission rate accordingly. Third, TCP Vegas has an efficient slow-start mechanism which avoids packet losses while trying to determine the available bandwidth (Brakmo et al., 1994). In addition, whenever packets are sent by the sending host, TCP Vegas examines these RTTs (propagation delay) and checks the size of its window. TCP Vegas detects that the network starts to be congested and limits the size of the window when RTTs take large values, and it is assumed that the network is free of congestion and increases again the size of the window when RTTs take this time small values and the window size is updated in the congestion avoidance phase as described in the equations (1), (2) and (3).

$$if\left(diff < \frac{\alpha}{base\_rtt}\right) \tag{1}$$

$$cwnd\left(t+t'\right) = cwnd\left(t\right)+1$$

$$if\left(\frac{\alpha}{base\_rtt} \le diff \le \frac{\beta}{base\_rtt}\right) \tag{2}$$

$$cwnd\left(t+t'\right) = cwnd\left(t\right)$$

$$if\left(diff > base\_rtt\right) \tag{3}$$

$$cwnd\left(t+t'\right) = cwnd\left(t\right)+1$$

with

$$diff = \frac{cwnd\left(t\right)}{base\_rtt} - \frac{cwnd\left(t\right)}{rtt\left(obs\right)}$$

α = is a constant

β = is a constant

$base\_rtt$ = is the smallest value of observed $RTTs$

$rtt\left(obs\right)$ = is the observed round trip time

For our second choice, which is TCP New Reno, its default mechanism relies on the size of the window which is changed cyclically in a typical situation since its window size continues to increase until the packets are lost. Two phases can be distinguished where the window size of TCP New Reno is increased, firstly in the slow start phase and secondly in the congestion avoidance phase. When at the instant $\left(t+t'\right)$ TCP receive an

ACK packet (acknowledgment) the size of the current window $cwnd\ (t+t')$ is updated from $cwnd(t)$ for each different phase as follow:

For the slow start phase

if $cwnd(t) < ssthresh(t)$

$$cwnd(t+t') = cwnd(t)+1$$

For the congestion avoidance phase

if $cwnd(t) > ssthresh(t)$

$$cwnd(t+t') = cwnd(t)+1$$

with, $ssthresh(t)$ which represents the phase change value of TCP from the slow phase to the congestion avoidance phase.

$$\begin{cases} cwnd(t) = 1 & \text{When packet loss is detected by} \\ ssthresh(t) = cwnd(t)/2 & \text{retransmission timeout expiration} \end{cases}$$

$$\begin{cases} cwnd(t) = ssthresh(t) & \text{When TCP detects packet loss} \\ ssthresh(t) = cwnd(t)/2 & \text{by a fast - retransmit algorithm expiration} \end{cases}$$

3.3 Metrics

UWSNs are much more challenging than traditional wired networks due to many factors including the mobility of the nodes due to underwater currents. Hence, it is important to understand the performance of TCP with variation in mobility. We have used here some basic metrics to analyse our simulated scenarios. The TCP throughput, the packet delivery ratio and the end to end delay were the measures used for performance evaluation. We can describe these metrics as follows:

- TCP Throughput as described in the equation (4) refers to the amount of delivered packets to our underwater sink divided by the total time taken.

$$Th(bits/s) = \frac{DP * PS^{8}}{TTS} \tag{4}$$

with,

Th: Throughput (bit/s).

DP: Delivered Packets.

PS: Packet Size.

TTS: Total Time of Simulation

The Packet Delivery Ratio (PDR) is described in equation (5), its value presents the proportion of received data by the underwater sink and those generated by the different source nodes as recorded in the trace file (Singh and Singh, 2009).

$$PDR = \frac{RSP}{TSP} \tag{5}$$

with,

PDR: Packet Delivery Ratio.

SRP: Successful Received Packet.

TSP: Total Sent Packet.

The End to End Delay (E2ED) reports the average duration it takes for a packet of data to arrive from source nodes to the underwater sink, and it is calculated as follows:

$$E2ED = \frac{ATD}{TSP} \tag{6}$$

with,

E2ED: End to End Delay.

ATD: Packet's Average Time Duration to rich destination .

TSP: Total Sent Packet.

4 Simulation setup

Performing real-life experiments is quite challenging and costly in underwater environments, therefore, we resort to simulations. We used Aqua-sim environment based on NS-2.30 to simulate our proposed scenarios. Aqua-Sim, for aquatic networks is a simulation tool for acoustic signal attenuation and packet collisions in UWSNs (Xie et al., 2009). Further, Aqua-Sim is coded with the same code languages as NS2.30 namely Otcl and C ++ which makes integration with it very convenient and easy for accustomed NS2 users, in addition, whatever changes are made in the wireless package it cannot affect it since all its files are independent, nor NS-2 packages and vice versa (Xie et al., 2009).

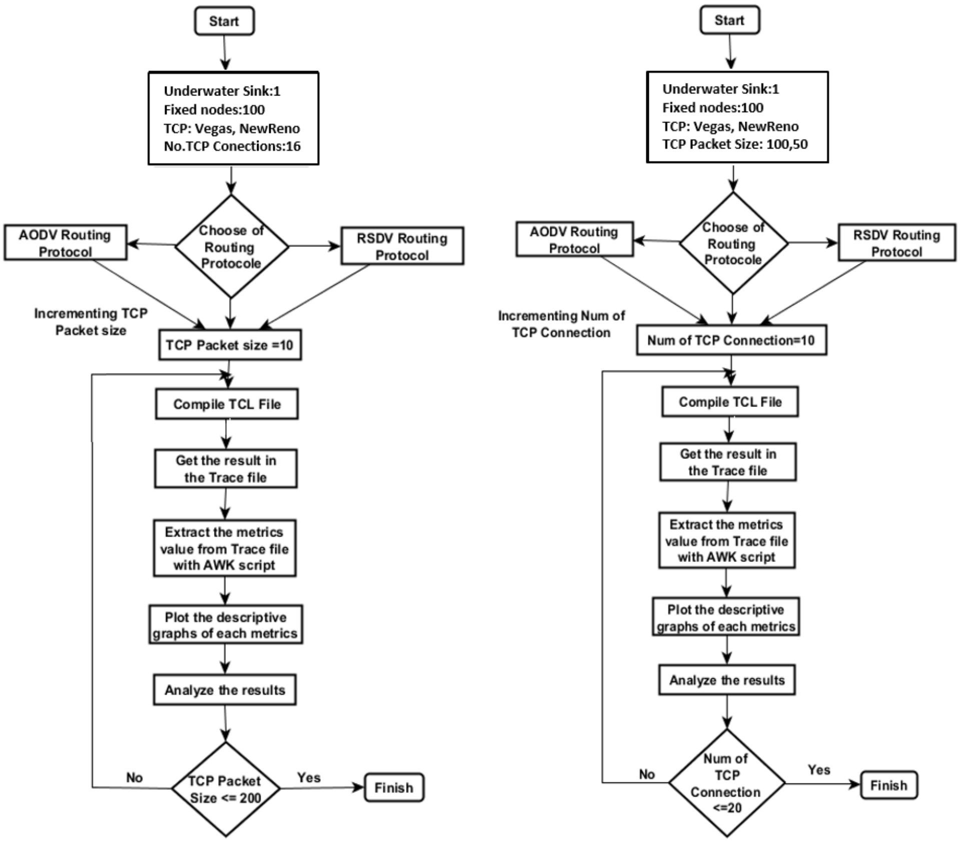
In this paper, we considered two main different scenarios to measure the aforementioned metrics and we set the experiment parameters according to Table 1.

Table 1 Simulation parameter

Parameter	*Value*
Channel	UnderwaterChannel
Propagation	UnderwaterPropagation
PHY	UnderwaterPhy
Antenna	OmniAntenna
Distance	75 m, 84 m
Frequency	25 khz
MAC protocol	BroadcastMac
Mac_bit_rate	10kbps
Delay	25 us
Routing protocols	AODV/DSDV
TCP agent	Vegas
Simulation time	500 s

- The first scenario as depicted in the flow chart in Figure 2(a) describes the study of the impact of varying TCP Packet Size of Vegas and New Reno while using DSDV and AODV routing protocols. The network starts with a value of TCP Packet Size equal to 10; this parameter takes the values of, 50, 100, 150 and 200.
- The second scenario as illustrated in Figure 2(b) is interested in studying the behaviour of TCP Vegas and TCP New Reno when changing the number of TCP connections in the underwater network, and it is also performed with AODV and DSDV routing protocols. We start with 8 as initial value of the number TCP connections and after each simulation we measure the value of each Metric then, we increment the number of TCP transmitters by 2 and we repeat the simulation until the last value of TCP connections number which is equal to 20.

Figure 2 Flow chart of our scenarios



a) First scenario b) Second scenario

5 Results and discussion

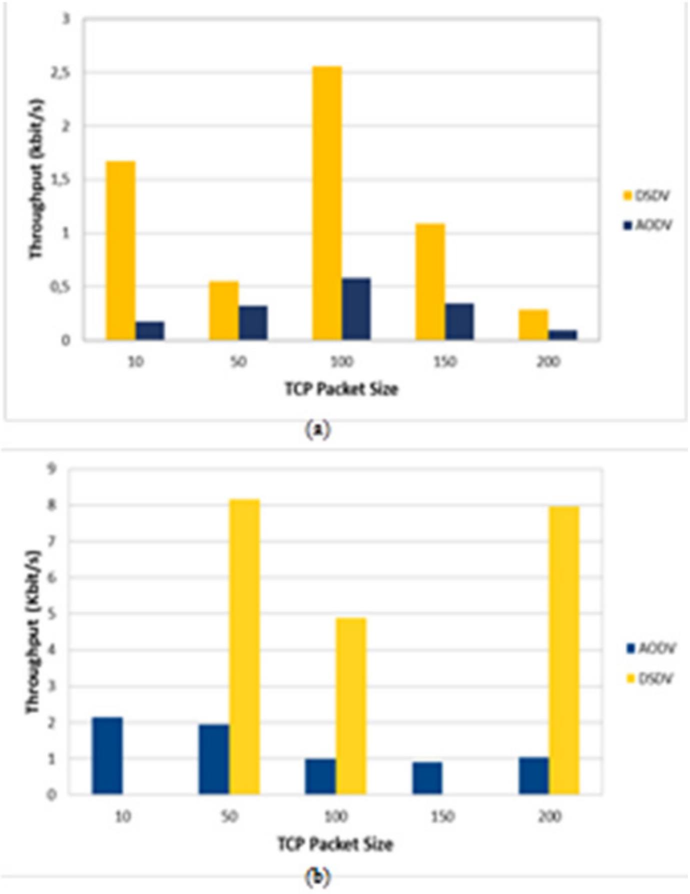
This section reports the simulation results and analysis of different scenarios studied in this work.

5.1 Varying the TCP packet size

This scenario presents the measures of throughput, PDR and end to end delay while varying TCP packet size. For both variants of TCP, Vegas and New Reno, we fixed the size of packet in TCP sink to 250 and we simulate with 16 TCP connections in a network of 100 nodes.

We started by calculate the average throughput described in (1), the results are depicted in Figure.3 where the evolution and behaviour of TCP Vegas and New Reno describe the average throughput while varying the TCP Packet Size.

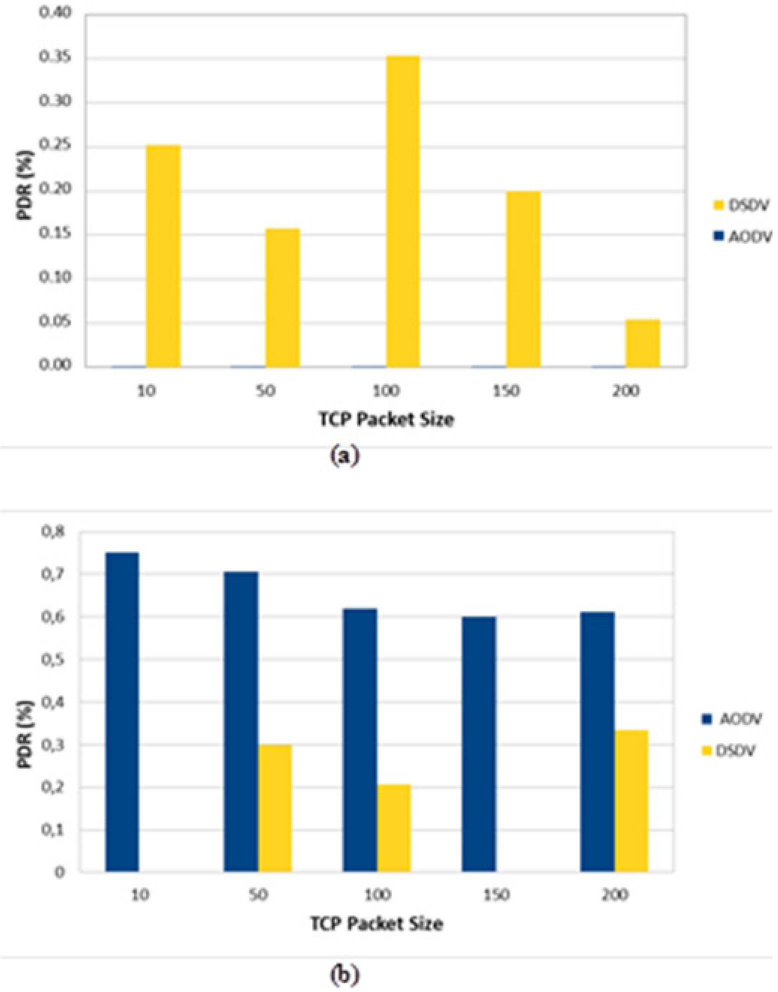
Figure 3 Throughput of (a) Vegas (b)New Reno



It is clear that throughput with DSDV is much better than the throughput with AODV. Both of them give us the highest performance with a value of 100 as Packet Size.

Figure 4 depicts the evolution of PDR while Packet Size increases from 10 to 200. As we can observe with (a) TCP Vegas no change has been noticed for AODV but this variation did affect DSDV which gave us good results and especially with the value of 100. The delivery ratio is more than 35% of packet delivering with DSDV when the packet size is equal to 100.

Figure 4 Packet delivery ratio of (a) Vegas, (b) New Reno



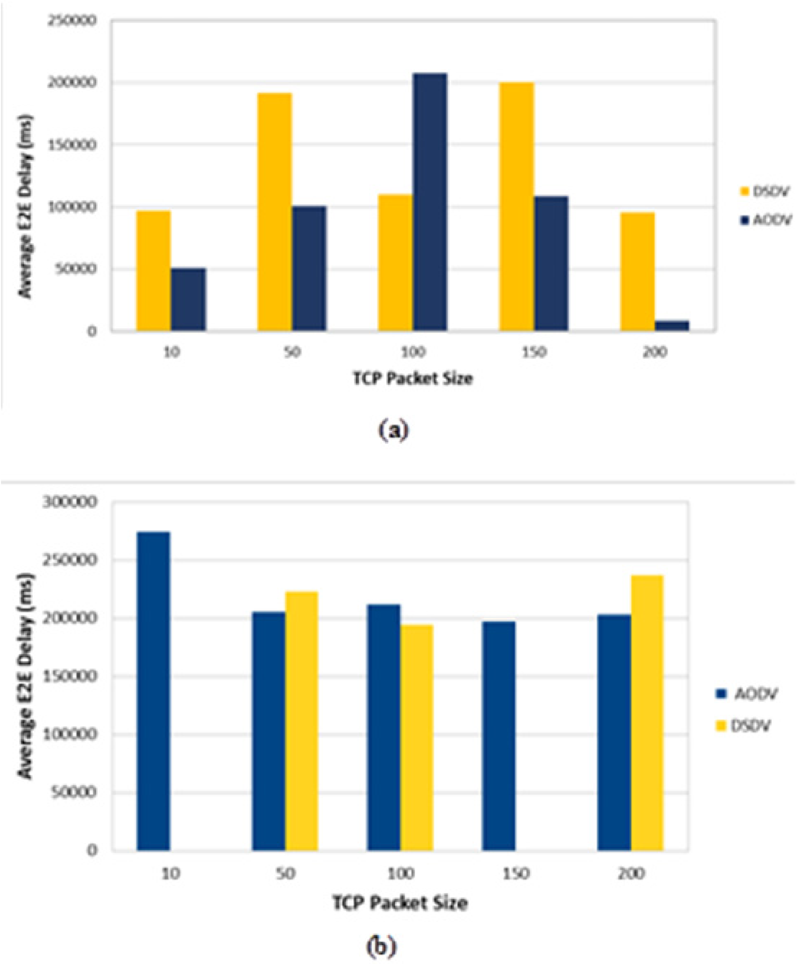
(a)

(b)

In (b) TCP New Reno, higher PDR is given while using AODV Routing Protocol which takes up 70% when Packet Size is 10, in other hand, the DSDV routing protocol allows New Reno TCP to reach 35% of delivering packet.

Figure 5 indicates the average end to end delay of TCP (a) Vegas and (b) New Reno which are roughly similar for the two routing protocols. With AODV as Routing Protocol, it is clear that it takes a slightly longer time because it needs to discover the routes before sending data which is not necessary for DSDV while increasing the TCP Packet Size.

Figure 5 Average end to end delay of (a) Vegas, (b) New Reno

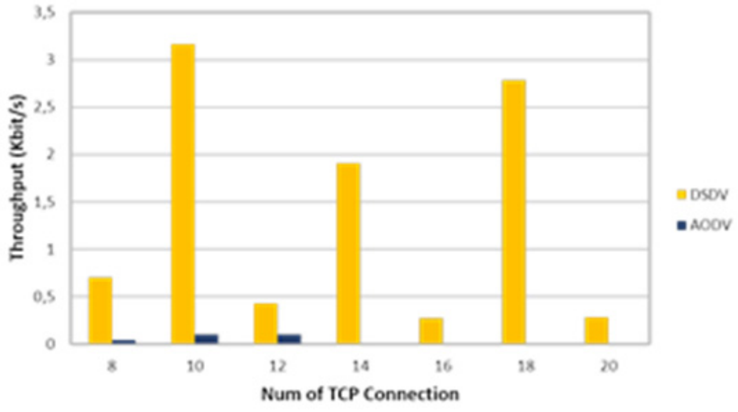


5.2 *Varying the number of TCP connections*

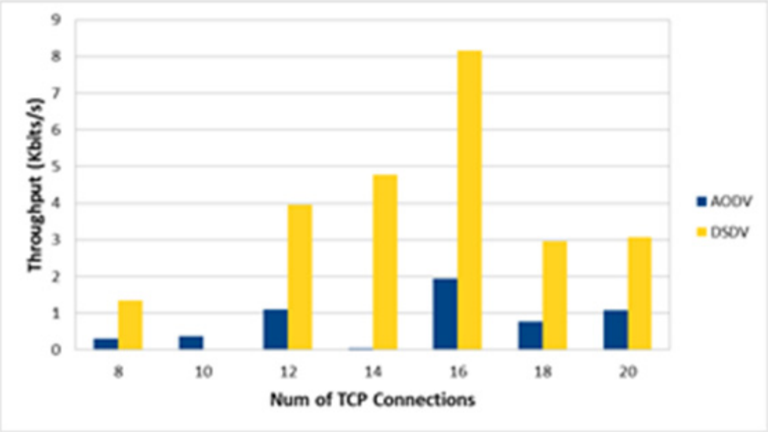
In the second scenario we evaluate the impact of TCP connections number, as we start our evaluation by simulating eight TCP connections in the network and we continue to increment until having 20 TCP connections with a network of 100 static nodes. The TCP Packet Size used with TCP Vegas is defined by 100 and with TCP New Reno is 50 based on the results of the first scenario where we found that those sizes yield good result regarding the number of transmitted packets with a good throughput.

The graphs in Figure 6 show that the best throughput for both Routing Protocols is obtained with 10 TCP connections in the network for (a) Vegas and increasing the number of TCP connections gives better throughput with a best value at 16 TCP connection in the network for (b) New Reno. And as we can see, the average throughput takes great values while using DSDV Routing Protocol in front of AODV Routing Protocol for both TCP Vegas and TCP New Reno.

Figure 6 Throughput of (a) Vegas, (b) New Reno



(a)



(b)

In addition, we note that the rate of throughput is more important with TCP New Reno which takes more than 8 Kbit/s in front of a maximum value of 3.2 Kbit/s for TCP Vegas.

The delivery ratio depicted in Figure 7 shows a large increase of delivered packets with (a) TCP Vegas while using AODV when increasing the number of TCP connection from 8 to 12. However, we can see that the best result for both protocols is obtained in 10 TCP connections, and goes to 12 TCP connections for AODV. With TCP New Reno, as depicted in (b) the PDR takes best results with 16 TCP connections for both Routing Protocols 0.3% of delivered packet with DSDV and 0.7% with AODV.

Figure 7 Packet delivery ratio of (a) Vegas, (b) NewReno

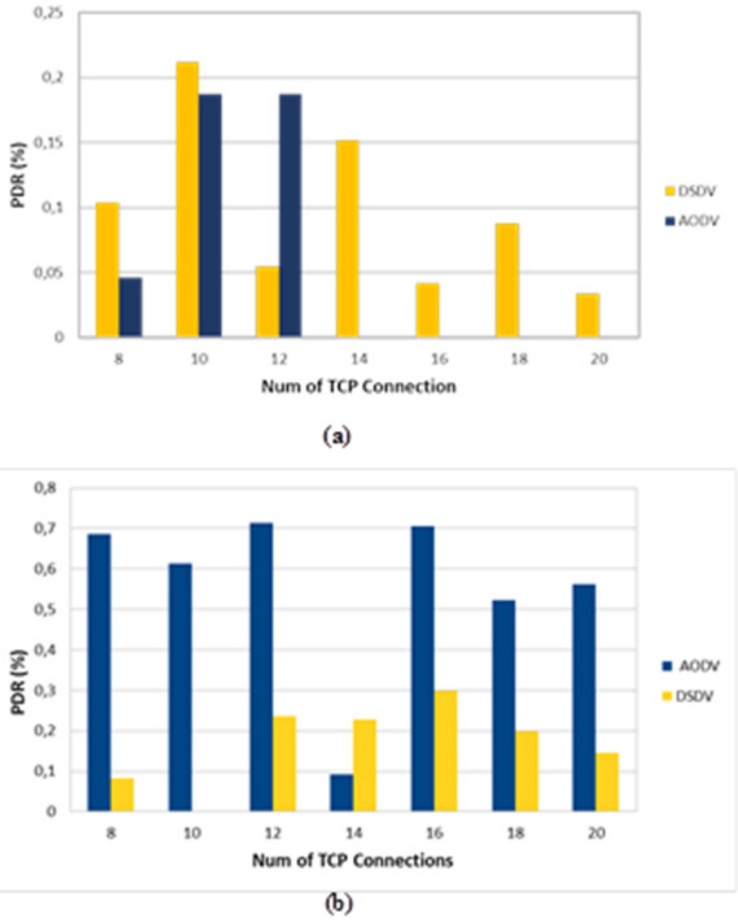
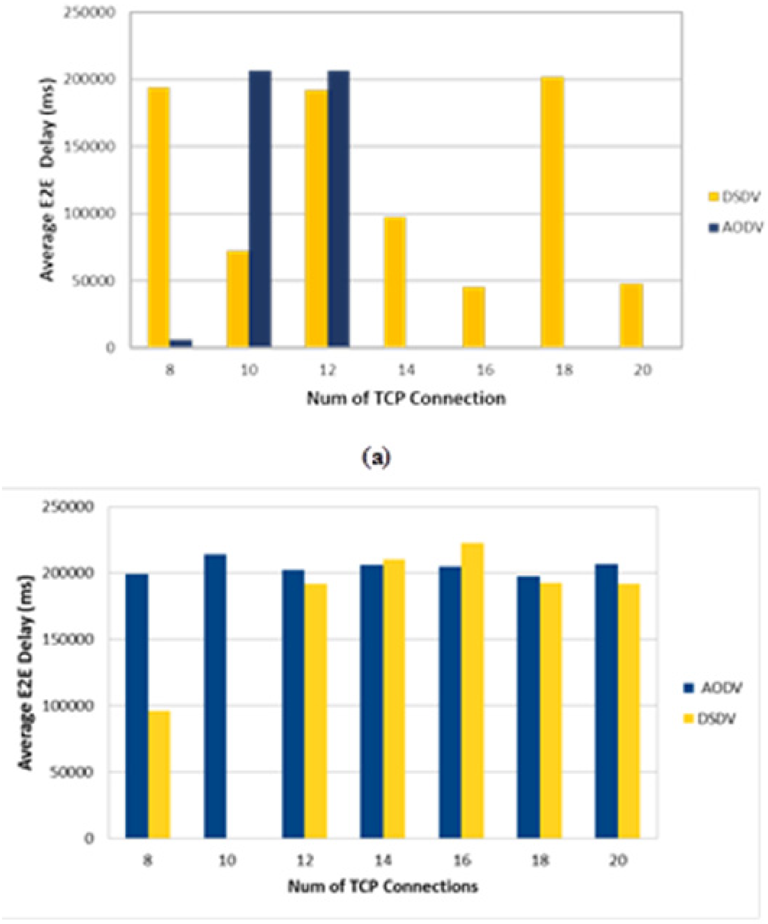


Figure 8 describes the average end to end delay where, using both routing protocols give a similar progression in general while number of TCP connections increase but due to the reactive nature of AODV the average end to end delay exceeds.

Figure 8 Average end to end delay of (a) Vegas, (b) NewReno



(a)

(b)

6 Conclusions

In this paper, we investigate the performances of two different TCP congestion mechanisms: TCP Vegas and TCP New Reno in Underwater Wireless Sensor Networks. In this study we used two different scenarios to evaluate the impact of varying TCP Packet Size and the density of TCP connections number in the network, since we believe that the choice of TCP Packet Size affects fundamentally TCP with different Routing Protocols, in this fact we used two different Routing Protocols AODV and DSDV to compare the performances of TCP Vegas and TCP New Reno.

Firstly, for TCP Vegas the variation of the Packet Size gives us a good throughput with the value 100 for both protocols, but the PDR remains intact for AODV and gives higher performance with DSDV with an acceptable average end to end delay.

Furthermore, a network of 10 TCP transmitters have a great PDR with both routing protocols and DSDV has a greater throughput than AODV. In the other hand, increasing the numbers of TCP connections affects the AODV Packet Delivery Ratio which increases comparing with the first scenario when the network has 8 to 12 TCP connections, but these results still remain poor in front of DSDV. On the other hand, for TCP New Reno we have observed that higher results are achieved with DSDV Routing protocol with a packet size of 50 and 200 even if the PDR with AODV is better, however the E2E delay remains almost equal with both Routing Protocols despite the change of the packet size.

Varying the number of TCP connections affects TCP New Reno, for both routing protocols the max value of throughput is found with a TCP Packet size of 50 and the results shows that DSDV gives higher throughput but AODV gives great PDR and in general the E2E delays with both routing protocols are still equal.

In this work, we were able to determine the number of TCP nodes we also define the TCP Packet Size value that give good performance for TCP Vegas and for TCP New Reno in a sub-sea network. In addition, we found that the most reliable routing protocol namely DSDV with 10 TCP Vegas connections and a value of 100 for the Packet Size was greater than AODV and for TCP New Reno, DSDV gives better results than AODV with 16 TCP New Reno connections using 50 for its Packet Size. On the other hand, we can see that when the number of TCP source is more than 12 then, the network throughput of TCP New Reno performs better than TCP Vegas since it reaches more than 8 Kbit/s while Vegas does not exceed 3.2 Kbit/s. New Reno and Vegas both achieved comparable average end to end delay. The results found with New Reno's parameters are more reliable to transmit more information than those transmitted with Vegas.

Our next steps will include studies on a large set of conditions, to get a general idea about the impact of these different conditions on TCP Vegas or TCP New Reno performances in a submarine environment, to come out with a new TCP protocol design which will be adapted to this special environment. And as it was introduced at the beginning of this work, our motivation comes from the long sea coasts that our country contains, which gives us several application domains to implement different underwater sensor networks whether for the aquatic fish farming or for climate monitoring and maritime pollution to enable regular monitoring of this environment and test our protocols.

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