A Study on Performance of CUBIC TCP and TCP BBR in FANETs

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الملخص

أصبحت الشبكات الادهوك اللاسلكية الجوية (FANETs) مؤخرا تحظي باهتمام كبير فيما يتعلق بالتقدم التكنولوجي في مجال الشبكات نقل البيانات اللاسلكية وقد استخدمت في أغراض مختلفة بما في دلك الأغراض ا لعسكرية والمراقبة خصوصا في المناطق التي لا يستطيع الانسان الوصول اليها. ومع تزايد الطلب علي شبكات الادهوك اللاسلكية جوية بحيث يمكن ان يعتمد عليها في تأمين الاتصال و نقل البيانات بين المركبات الجوية, أصبحت الأبحاث العلمية في هدا المجال ضرورة ملحة من اجل الوصول الي تصميم برتوكولات جديدة او استعمال بروتوكولات الحالية والتي يتم استخدامها في أنواع اخري من شبكات نقل البيانات، حيث قام العديد من الباحثين بالتحقيق في بروتوكولات التوجيه (Routing protocols)، بينما علي حد علمنا لا يوجد تقييم لبروتوكولات TCP في FANETs وعلي هذا الأساس قمنا في هذه البحث بدراسة وتقييم أداء بروتوكولي TCP-CUBIC و TCP-BBR ، و اللذان حديثا اصبحا يستخدمان على نطاق واسع كأحدي بروتوكولات التحكم في الازدحام TCP, باستخدام برنامج محاكاة (NS-3) Network simulator-3. لمعرفة مادا كانت هده البروتوكولات يمكن استخدامها احداها في (FANETs). كبرتوكول التحكم في نقل البيانات ام لا. وقد قمنا قياس كلا من الإنتاجية (Throughput) وكذلك كلا من مؤشر الانصاف (Fairness Index) وزمن التأخير (Time delay). في حالة التغيرات في عدد المركبات الجوية وكدلك في حالة التغيرات في قيمة سرعة المركبات الجوية. ومن خلال النتائج أتضح لنا أن أداء كلاهما ضعيف على الرغم من أن TCP-CUBICأفضل بقليل من ناحية الأداء من. TCP-BBRوبالتالي لا يمكن الاعتماد عليهم.

Abstract

Flying ad-hoc networks (FANETs) recently have paid attention regarding to technological progress in the field of wireless network, it has proposed for various purposes including military, surveillance and monitoring of areas, where it is unreachable by a human. With the high demand for continues network connectivity with reliable and robust communication becomes a challenging research topic. In addition, the investigation of routing protocols has done by many researchers, while, to our knowledge, there is no evaluation of TCP protocols in FANETs. According to those issues in this paper, we study the performance behaviors of TCP-CUBIC and TCP-BBR protocols, which are most widely used as a TCP congestion control protocol and most getting attention recently. As well as this study, concern with the investigation whether any of those TCP protocols could provide significant performance benefits over FANETs. Those protocols have evaluated using Network simulator-3 (NS-3), and we have compare the protocols using throughput and Fairness Index under different moving speeds of UAVs and under variety of number of UAVs.

As a result, that, those TCP protocols have a poor performance, Although, TCP-CUBIC slightly better performance than TCP-BBR on average, but none of them can help to provide reliable and guaranteed end-to-end data delivery.

Keywords:- FANETs,NS-3,TCP-BBR,TCP-CUBIC.

1. Introduction

The research community around the globe paid more attention to flying ad-hoc networks (FANETs), in recent years, due to their advantages in wide range of applications such as: military Services, Security maintenance, calamity administration and Search/Rescue Operations.

FANET is type of ad-hoc networks, formed in the sky among highly mobile flying nodes (i.e. drones).It has featured by self-configuration and self-organization (Lakew, et al., 2020; Oubbati, et al., 2019). The FANET offers infrastructure less environment with more flexible and dynamic topology. The most known example of FANETs are wireless networks have made by an incorporate a group of UAV (Unmanned Aerial Vehicle), A typical architecture of FANET has shown in Figure 1.

The UAV offer advantages of small size, low cost, fast motion and working efficiently in both individual and group manners (Chriki, et al.,2019). There are some limitations of UAVs, which discussed in literature for future research work (Nawaz, et al.,2020;Sang, et al.,2020).This includes ensuring reliable connection between the UAVs. The most researchers have investigated the routing protocols in network layer, but there is no attention paid to the transport layer and its associated protocols in FANETs, and it is still an open research issue (Gankhuyag, et al.,2017; Zheng, et al. ,2018).

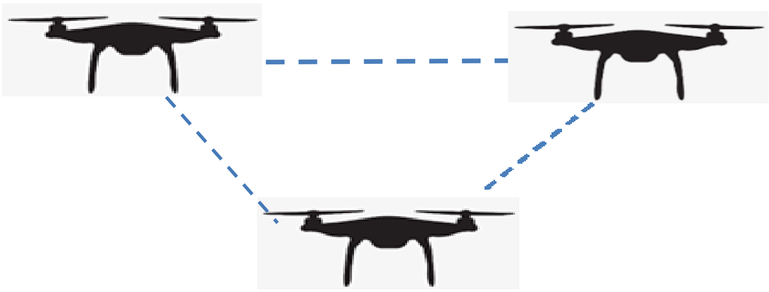

Figure1. Flying ad-hoc network.

In transport layer, there are two main protocols in transport layer, which used intensively in network communication context; they are User Datagram Protocol (UDP) and Transmission Control Protocol (TCP). TCP outperforms UDP in providing more reliable and guaranteed end-to-end data delivery over unreliable network. Therefore, we will focus on the implementation of Transmission Control Protocols.

The TCP protocols has used to carry the most of internet traffic over internet When the traffic offered to the network exceeds the available capacity then, the congested is occur to the network. With control of congestion, the traffic can be controlled when enter the network.

Congestion control functions have introduced by Van Jacobson(Jacobson, et al.,1988), he has proposed three algorithms for congestion control and avoidance: congestion avoidance (Congestion Avoidance algorithm, also known as Additive Increase/Multiplicative Decrease (AIMD) algorithm), slow-start and fast re-transmission.

Later on, many TCP congestion controls have proposed, wherein several modifications have undergone to improve the performance of TCP on different types of communication networks with large congestion window (cwnd) (Floyd, et al.,2003; Mascolo, et al.,2001;Liu, et al.,2010; Brakmo,et al.,1995; Ha, et al.,2008; Lisong, et al.,2004;Cardwell, et al.,2016), Although of that, those protocols have struggling to deal with different network environments, each type has own problems and limitations that different from one to another network.

Up to our knowledge, there is a research gap of not examining the impact of TCP protocols on UAVs networking performance. We argue the TCP protocols need to be investigate by simulation to bridge this gap and to advance the FANETs application domain.

In this paper, we study the performance of TCP protocols at the transport layer and especially on two types of TCP protocols, they are: TCP-CUBIC (Ha,et al.,2008)and TCP-BBR(Cardwell, et al.,2016).

We implemented this simulation by using network Simulator-3(NS-3),(https://www.nsnam.org).for performance studying. The rest of this paper has organized as follows: section 2, has given an overview on the protocols that have tested in this paper, Section 3 describes the experiments, including the implemented simulation and the experimental setup for the evaluation of the proposed investigating approach. Section 4 discusses the experimental simulation results, while Section 5 concludes the paper.

2. Related work

Several research studies have analyzed BBR and cubic (Li,et al.,2018; Zhang,et al.,2019; Kanaya,et al.,2020; Atsuta,et al.,2020) performance in different scenarios and technologies but none of them has analyzed those protocols in FANETs.

2.1 TCP CUBIC

TCP-CUBIC is enhanced version of TCP-BIC (Xu,et al.,2004) that has proposed in 2005, it has designed to overcome the RTT unfairness problem by increment cwnd size independent of RTT(round trip time). The two algorithms have combined called binary search increase, and additive increase. The Binary Search Increase ensures TCP- friendliness, when cwnd size is small; while additive increase ensures linear RTT fairness when cwnd is large, such that cwnd size will increase aggressively if it is far from equilibrium and slowly if it is close to equilibrium("a connection is said to be in equilibrium if it is running stably with a full window of data in transit" (Jacobson,et al.,1988) during the steady-state. Although, TCP-CUBIC has made further improve than TCP-BIC, but TCP-unfairness problem has not addressed by it, many details of this protocol is available at (Ha,et al.2008).

2.2 TCP BBR

TCP-BBR (Cardwell, et al.,2016),proposed by google in late 2016, recently, many Linux's distributions uses the it as default TCP; it differ from TCP-CUBIC and other protocols, that rely on loss as indicator for congestion, in TCP-BBR, the network model has created by continuously measured both round-trip propagation delay(RTprop)and available bandwidth at the bottleneck link(BtlBw). The TCP-BBR has two parameters used to control sending rate, congestion window (Cwnd)and pacing rate which have calculated as following:-

$$BDP=BtlBW*RTprop \quad (1)$$

$$Cwnd=G*BDP \quad (2)$$

$$\text{Pacing rate}=G*BtlBW \quad (3)$$

Where, the BDP has defined as the Bandwidth Delay Product (BDP), and G is defined as gain coefficients (Scholz.et al.,2018).TCP-BBR has four states: Startup, Drain, Probe Bandwidth, and Probe RTT. The states have switching based on the values of BtlBW and Rtprop, many details of this protocol has available at (Cardwell et al.2016).

3. Simulation Environment

The experiments have conducted, using NS-3.30.1 simulator, the results obtained for TCP BBR and TCP CUBIC compared between them. All simulation parameters, which have applied in this simulation environment, have given in the Table 1 and the simulation topology has illustrated in figure 2.

Table 1. Simulation Parameters

Parameter	Value
Application Type	FTP(File transfer protocal).
Number of TCP connections.	5,10,15,20,25.
Routing Protocols.	AODV.
Simulation time.	100 seconds.
Packet Size.	1448 bytes.
Transmission Rate.	100Mbps.
Simulation area.	400m × 400m×100m.

Parameter	Value
Speed of UAVs	5,10,15,20,25 (m/s).
Number of UAVs	20,30,40,50,60.
Propagation Loss Model	Log Distance Propagation Loss Model.
Propagation Delay	Constant Speed Propagation Delay.
Physical layer	OFDM with 24MBps
Physical Rate	24Mbps.
Mobility model.	Guass Markov
MAC layer.	IEEE 802.11n with 5.
Antenna model.	Omni Antenna.
Rto (retransmission timeout)	1s

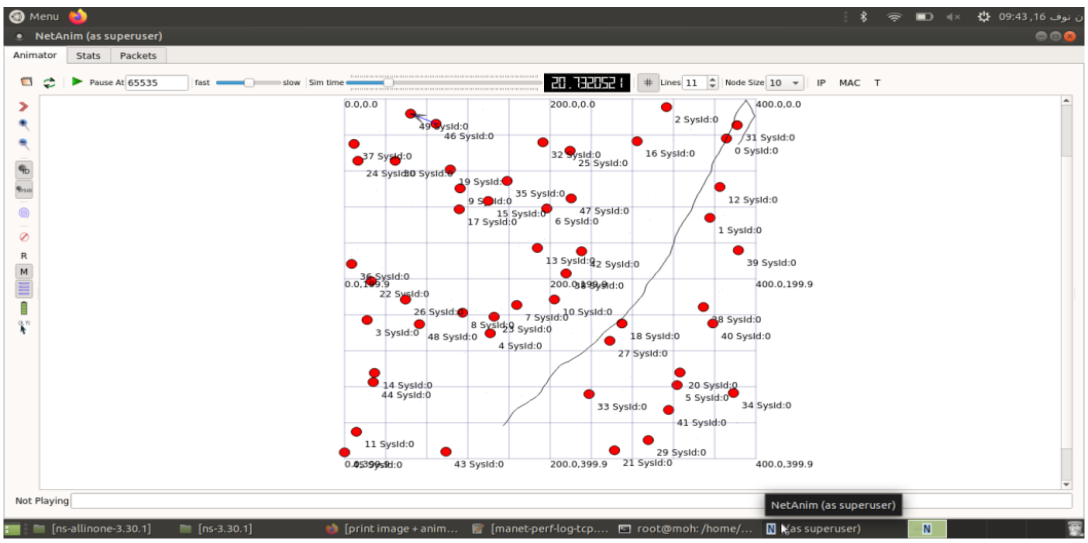

Figure.2. simulation topology.

4. Performance Metrics:

In this section, we introduce the following metrics of interest to evaluate the performance of the selected congestion controls protocols described in this work:-

4.1. Average Throughput:

It is the ratio of the total number of delivered successfully data packets to destinations UAVs and the time difference between received data packets and transmitted data packets.

$$\text{Averagethroughput(kbps)} = \frac{\text{TNSP}}{\text{TR}-\text{TS}} \qquad 4)$$

Where, TR is time of received data packet, TS is time of sent data packet and TNSP is Total number of successfully received data packets.

4.2. Fairness:

We use the Jain index for measuring fairness metric given by Equation 2, where xi is the throughput experienced during a particular flow i to measure fairness. This matric has suggested in(Huaizhou,et al.,2013) and n is number of flows.

$$\text{Fairness}=\frac{(\sum_{i=0}^{n} x_i)}{n\sum_{i-0}^{n} x_i} \quad 5)$$

1. Simulation Results and Analysis

The simulation experiments have conducted for two different scenarios as follows:

1) Impact of varying density of UAVs.
2) Impact of varying speed of UAVs.

1) Test 1: Impact of varying density of UAVs.

To investigate the impact of network density, the number of UAVs have varied from 40 to 80. The maximum speed of mobility of UAVs have fixed to 25 m/s and number of flows has fixed to 30. The results of this scenario are shown in figure 3 and figure 4.

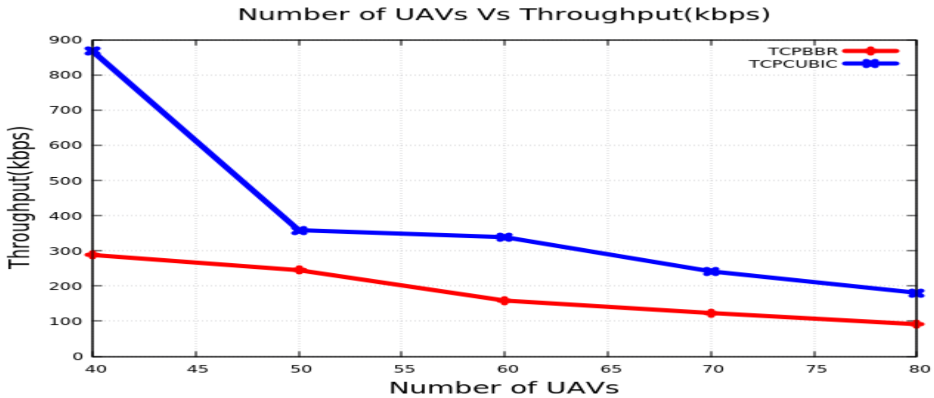

Figure 3: Throughput vs. Density of UAVs.

From the figure3, it can be observed that TCP throughput highly degrades with increased node density of UAVs, which has proven the poor performance for both protocols.

The different errors in the wireless channel makes it hard for TCP-BBR and TCP-CUBIC for deciding the value of *cwnd,* further, these protocols fails to distinguish between the packet losses due to congestion and the packet losses due to link failures, however, TCP CUBIC has higher throughput than TCP-BBR in all different numbers of UAVs.

The maximum throughput has reached for TCP-BBR is 288.185 kb/s while the maximum throughput for TCP-CUBIC is 867.729 kb/s when the number of UAVs is 40, while the minimum throughput has reached for TCP-BBR is 91.271 Kb/s and minimum throughput for TCP-CUBIC is 180.579 kb/s when the number of UAVs is 80.

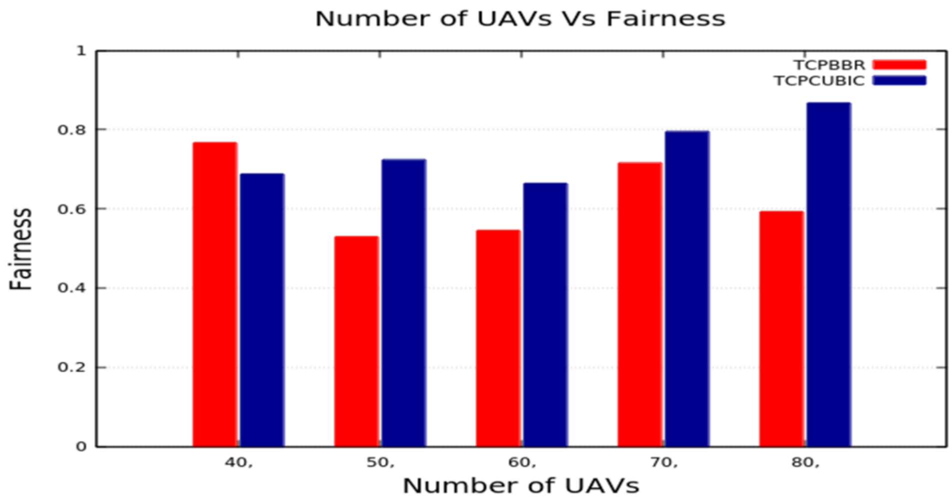

Figure4 Fairness vs. Number of UAVs.

It can be seen, from figure 4, there are variations in the graph, of fairness index, and it is very hard to achieve fairness between the flows because the difference in RTT flows.

However, the TCP-CUBIC has higher fairness index than TCP-BBR in the most number of UAVs.

The maximum value of fairness index for TCP-BBR is 0.7675, when the number of UAVs is 40, and the minimum value is 0.5295 when the number is 50.

While in TCP-CUBIC the maximum value of fairness index is 0.8671, when the number of UAVs is 80, and the minimum value for fairness index is 0.6642 when the number of UAVs is 60, from those results.

We can conclude there is no relationship between increasing the number of UAVs and the fairness index for both protocols; hence, both protocols are struggling in maintaining fairness between the flows.

2) Test 2: Impact of varying speed of UAVs.

In this scenario, the effect of the speed of UAVs has observed by varying the maximum speed from 5 m/s to 25 m/s with increments of 5 m/s. The number of the flow connections between source and destination has fixed to 30, and number of UAVs has fixed to 60 too. The results of this scenario have shown in figure 5 and figure6.

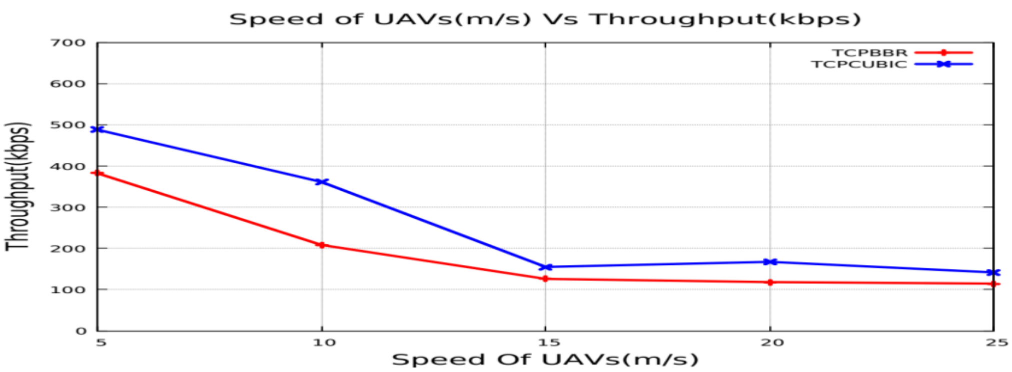

Figure 5. Throughput .vs. Speed of UAVs.

Figure 5, shows that throughput, has degraded with the increase in speed of UAVs. The TCP protocols are suffer from frequent route failures which occur, due to the mobility of UAVs, and those protocols, do not have indications on route re-establishment event after disconnected the route, when a new route is established the time taken for that is long, hence, the old route TCP will face a brutal fluctuation in RTT.

Further, the regular movement of UAVs, makes the network partition so the ACK packets will not receive properly, and it is clear those protocols did not handle these issues properly, however, TCP-CUBIC has higher throughput than TCP-BBR in all different numbers of UAVs. The maximum throughput has reached for TCP-BBR is 382.694 kb/s while the maximum throughput for TCP-CUBIC is 488.2kb/s when the speed of UAVs is 5 m/s, while the minimum throughput has reached for TCP-BBR is 114.5539 Kb/s and minimum throughput for TCP-CUBIC is 141.76 kb/s when the speed is 5 m/s.

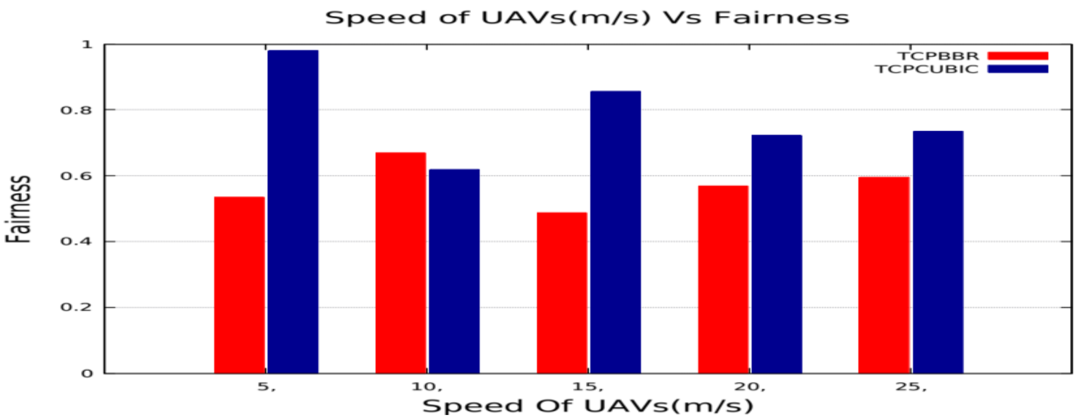

Figure6. Fairness vs. Speed of UAVs

The Fairness for this scenario has shown in Fig. 6. This figure reveals that TCP-CUBIC outperform TCP_BBR most of the speed the UAVs, we can observe from the figure, the value of fairness is not dependent on the speed of UAVs, it depended on RTT flows, such that the long RTT flows will require more bandwidth than short RTT flows at shared channels.

The maximum value of fairness index for TCP-BBR is, 0.67, when the speed of UAVs is 10m/s, and the minimum value is 0.487 when the number is 15 m/s.

While in TCP-CUBIC the maximum value of fairness index is 0.98046, when the speed of UAVs is 5m/s, and the minimum value for fairness index is 0.618 when the speed of UAVs is 10 m/s.

Conclusion

The objective of this study is to evaluate the performance of two prominent TCP protocols in FANET, from the results; we demonstrate that TCP-BBR and TCP-CUBIC, have poor efficiency.

This gives us an open issue regarding to modify those protocols for making ability for distinguishing between packet losses caused by transmission errors from network congestion and has facility to provide a better quality of services (QoS) to guarantee transmitting a different type of data in FANETs.

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