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Congestion Control Protocol for Future Networks (DCM+)

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Abstract

This paper proposes a new approach for TCP congestion control for future data networks, which is called TCP DCM+. DCM is the previous version, which uses TCP Westwood method of estimating the available bandwidth. The aim of the new protocol is to improve the performance and stability of DCM through using the corrected algorithm in TCP Westwood+ to estimate the available bandwidth. DCM+ is rate-based end-to-end approach, which applies the modification in both phases (SS, CA) of the sender. The results of the simulations show a huge improvement of throughput, in addition to the resulting stability. Many experts believe that the future of computer technology rests in mobile computing with wireless networking. TCP DCM+ is designed to be applicable in wired, wireless and MANETs networks. The simulations executed here are done using ns-3 simulator [16].

Keywords: DCM, DCM+, Westwood+, Congestion Control, Bandwidth Estimation, Mobile Networks.

I. INTRODUCTION

In the future, the congestion-avoidance algorithm is the primary basis for congestion control in the Internet, for increasing utilization. Congestion control is so important for data networks, and especially for TCP systems [11]. It is vital for achieving the expected performance and high throughput, and therefore, keeping our digital world away from collapse. A lot of protocols since 1986 have been designed and enhanced [2]. Some of these protocols were more appropriate for specific types of networks. TCP Westwood [3] was a great step toward sender-side modification to mitigate congestion events, without any notifications from intermediate devices (routers).

TCP Westwood+ is the corrected version of TCP Westwood. TCP Westwood technique was not accurate enough for estimating the bandwidth [8,9]. This paper is divided into many sections. Section I is the Introduction of the paper. In section II, we present other works related to congestion control. In section III, we introduce the proposed TCP DCM+ Protocol. Section IV describes the simulation environment. Section V presents the simulations and their analysis. At the end of the paper, in section VI, we have our conclusion.

II. RELATED WORKS

The most prominent protocol studied and used for congestion control till short time ago is TCP NewReno. Its last modification came in the year 2012 as RFC 6582. The advantage of NewReno lies in its ability to detect multiple packet losses. The limitation of NewReno is that it cannot distinguish the cause of packet loss, thus, a more effective fast recovery algorithm cannot be implemented [4]. Another disadvantage is little support for mobility [4,5,10].

TCP Westwood+ is a rate-based end-to-end (E2E) [2] approach, which has corrected the algorithm used in TCP Westwood for estimating the available bandwidth. It can be used in both wired and wireless networks [15]. In case of wireless packet losses, it just resends the lost packets, and does not behave like NewReno, which enters the congestion phase, and drops the cwnd value to the half.

TCP Westwood+ protocol is used to detect packet errors like arrival of 3 DUPACKs or a coarse timeout. The estimation of BW in TCP Westwood+ is done using a low-pass filter [6,7], which filters the rate of returning ACK packets. This algorithm adaptively sets new values for ssthresh and cwnd [8]. The same method will be applied for BWE in DCM+. DCM uses the Westwood algorithm described in [3]. The modifications in Westwood+ have solved the problems caused by ACK compression [6,12], thus we expect better performance for DCM+ compared with DCM. The following algorithm shows the steps executed in TCP Westwood+ protocol.

Algorithm 1 Westwood+ Algorithm

```
Input=in
Output=out
If (in = ACK) then
Estimate available bandwidth;
out = Increase cwnd according to NewReno;
end if
Else
If in = (3 DUPACKs) then
ssthresh=max (2, (BWE*RTTmin)/Seg_Size);
cwnd = ssthresh;
out = cwnd;
end if
Else
if in = (coarse timeout) then
ssthresh=max (2, (BWE*RTTmin)/Seg_Size);
cwnd = 1;
out = cwnd;
end if
return (out);
```

DCM protocol was initially proposed in 2015 by R. Hamamreh and M. Bawatna as congestion control protocol for MANETNs [1]. DCM is based on finding and using a newer path with less congestion from source to destination if a specified value of congestion threshold has been detected. DCM, as L4 protocol, when applied in MANETs [13], will require the cooperation with an L3 routing protocol such as **DYMO [13]**. The results of route request message are delivered from DYMO to DCM [1]. Based on those results, DCM will be able to early detect the congestion event. In this case, DCM as L4 protocol will ask L3 protocol to look for a newer path. Based on the results coming back from DYMO protocol, new values for (cwnd) and slow start threshold (ssthresh) will be calculated. The following equations are used in DCM to calculate the values of (cwnd) and (ssthresh) [1]:

Case 1: new path in MANET is found between source and destination:

$$CWND_{new} = \frac{RTT_{old}}{RTT_{new}} * ssthresh_{new} * \beta \tag{1}$$

In DCM, β has been found to be optimal for $\beta = 0.8$.

Case 2: no new path in MANET is found. Then we calculate new value of $\mathrm{CWND_{new}}$ based on the following equations:

$$\begin{cases} \mathrm{CWND_{old}} + \left(\frac{\mathrm{RTT_{old}}}{\mathrm{RTT_{new}}}\right) * 0.9 & ;\mathrm{CWND} < \mathrm{ssth} \\ \mathrm{CWND_{old}} + \frac{\mathrm{RTT_{new}}}{(\mathrm{CWND_{old}} * \mathrm{RTT_{old}})} & ;\mathrm{CWND} \geq \mathrm{ssth} \end{cases} \tag{2}$$

In the above cases, the value of *ssthresh* is calculated first based on the algorithm of TCP Westwood [3]. The disadvantage of this method is the inaccurate results of the available bandwidth, because this algorithm does not work correctly in the presence of reverse traffic due to ACK compression [8]. This can later lead to additional congestion events. The calculated values for ssthresh and cwnd in TCP Westwood are overestimated [5,6,7]. The calculations of **ssthresh** regarding

TCP Westwood protocol depend largely on BWE, which is described below:

$$BWE = \frac{ACK\_Size}{ACKInterval} \tag{3}$$

$$ssthresh = \max\left(2\,,\, \frac{BWE * RTTmin}{SegmentSize}\right) \tag{4}$$

It is obvious, that a precise value of ssthresh requires a precise algorithm for computing the available bandwidth. Inaccurate values of BWE cause inaccurate values of ssthresh, and thus wrong cwnd sizes. This is the main reason for instability and bad performance of both TCP Westwood and DCM. As a sequence, the resulting transmission will take longer to complete. The average delay and RTT values will then increase. The throughput/goodput will also suffer through the extreme up/down jumps of ssthresh, and there will be no clear steady state value for cwnd.

The mathematical analysis and experimental tests of TCP Westwood protocol as given in [5,6,9,10,14] verify the results we perceived from our simulations. These results will reflect on the behavior of DCM protocol.

The simulations of DCM show continuous fluctuations around the steady-state of cwnd, which is much lower than the real available ssthresh. DCM uses the layers 3 and 4 to mitigate the congestion events. If a congestion threshold is exceeded, then DCM asks L3 routing protocol (i.e. DYMO) to find another path with lower RTT between the same source and destination nodes. If this process succeeds, DCM changes immediately to the new path. This process has although many disadvantages, such as data buffering, delays and processing times in both layers. Therefore, it could be advantageous not to select a new path, but to try to avoid reaching the congestion threshold while staying on the same path [3,8,15]. This is exactly what will be done using DCM+ protocol, except in extreme cases in MANETs, when the path between source and destination is not functioning anymore [13].

DCM+ shows excellent properties, which make it applicable in wired, wireless and in MANETs networks. The simulations presented in this paper show excellent throughput, stability and congestion mitigation for DCM+ vs. DCM. Other properties like delay, goodput, and steady-state behavior are better than in DCM.

III. PROPOSED: DCM+ Protocol

DCM+ is an E2E approach, that uses the same algorithm explained in TCP Westwood+ to find the accurate estimation of available bandwidth on the link. It describes sender-side modifications of TCP NewReno protocol in either phases (SS and CA). From the discrete BWE values, DCM+ calculates the discrete values for ssthresh and cwnd for the next transmission. The behavior of cwnd in SS phase is observed to be dynamical, in that it linearly tracks the current state of ssthresh. If a change (increase or decrease) of ssthresh has been observed within a time interval, then DCM+ continues to use the current value of cwnd until a newer ssthresh has been used, then cwnd moves and stays at the new state of ssthresh for that time interval. This way, cwnd will never exceed the measured ssthresh value, and hence, congestion events will be extremely minimized. Steady-state and stability can be observed.

In CA-phase, a new parameter ($rate_{CA}$) for adapting the speed of transmission has been introduced.

$$rate_{CA} = \frac{RTT_{old}}{RTT_{new}} \tag{5}$$

RTT is calculated according to the Jakobson's algorithm [12]. Values larger than 1 are preferred. This tells, that increasing cwnd is possible, as the channel capacity of the used link is increasing. Note, that ($RTT_{new} < RTT_{old}$) means depletion of packets from the buffer of intermediate nodes. This parameter is also used to adjust the next discrete value of RTO on the same path. This adjustment allows an appropriate increase of throughput through minimization of congestion events.

$$RTO_{new} = RTO_{old} * \frac{RTT_{new}}{RTT_{old}} \tag{6}$$

The $rate_{CA}$ parameter is a good measure for selecting the appropriate path with less congestion in MANETs. If this parameter for path1 is less than for path2, then path2 offers better performance, and hence, can be selected. After calculating the next value for ($rate_{CA}$), and adjusting the RTO value for the next transmission, the congestion event will be treated based on the conditions given in (eq. 7), namely if cwnd is less or (greater/equal) than ssthresh. Here, we distinguish 2 cases for $CWND_{new}$ as given in DCM protocol, but with modified values of the constants:

$$\begin{Bmatrix} CWND_{old} + 2 * rate_{CA} \ ; & cwnd < ssthresh \\ CWND_{old} + \left(\frac{2}{rate_{CA} * CWND_{old}}\right) \ ; & cwnd \geq ssthresh \end{Bmatrix} \tag{7}$$

If 3-DUPACKS are detected, or in case of coarse timeout, the CA-phase will be entered, and the previous equations (eq. 5,6,7) will be used. The resulting values used to update ssthresh and cwnd are expressed as the number of packets during the next transmission. The working of DCM+ protocol is shown below.

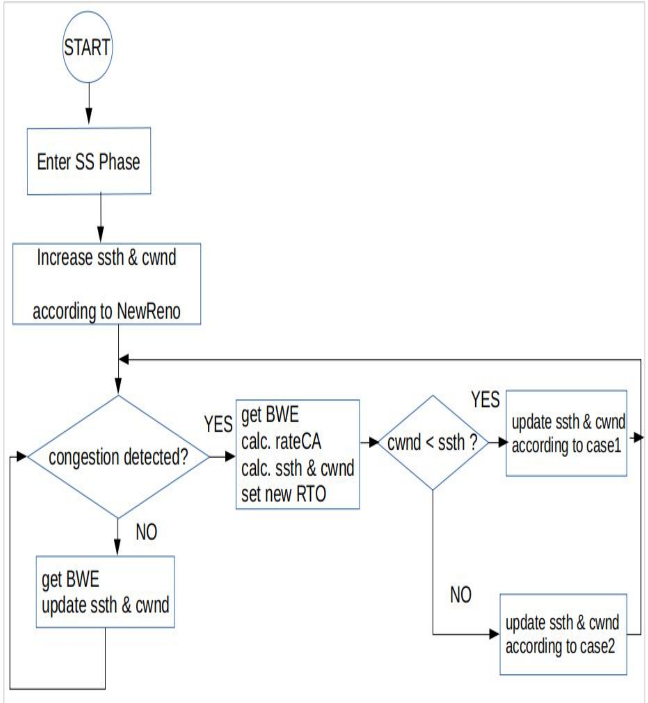

Fig. 1: DCM+ Protocol Flowchart

IV. SIMULATION ENVIRONMENT

We used Linux Ubuntu 18.04 as simulation environment. It has been installed as a virtual machine inside VirtualBox 5.2.20. The channel of this path may be wired or wireless. The behavior of DCM+ is measured for error rates in the range (0.00001, 0.01, 0.02, 0.03, 0.04, 0.05 and 0.1) and data sizes ranging from 1 KB up to 10MB, and for different MTU sizes from 400 bytes up to 1500 bytes. Targeted protocols, that have been tested are (Westwood, Westwood+, NewReno, DCM and DCM+). The simulations are done in ns3 [16] for many cases with different parameters like: error rate, channel bandwidth, size of sent data, segment size and protocol.

Main parameters, that have been used in our simulation are the shown below, but not all simulations are shown in this paper.

- Packet error rate,
- Protocol (WW, WW+, DCM, DCM+, etc.),
- Data size,
- Maximum Transmission Unit (MTU)

- Bandwidth,
- Delay,
- Duration of simulation.

V. SIMULATION RESULTS

In the followings, the figures are generated using ns-3.29 simulator, and then plotted for different network parameters using the Linux utility "Gnuplot". The parameters used in this simulation are:

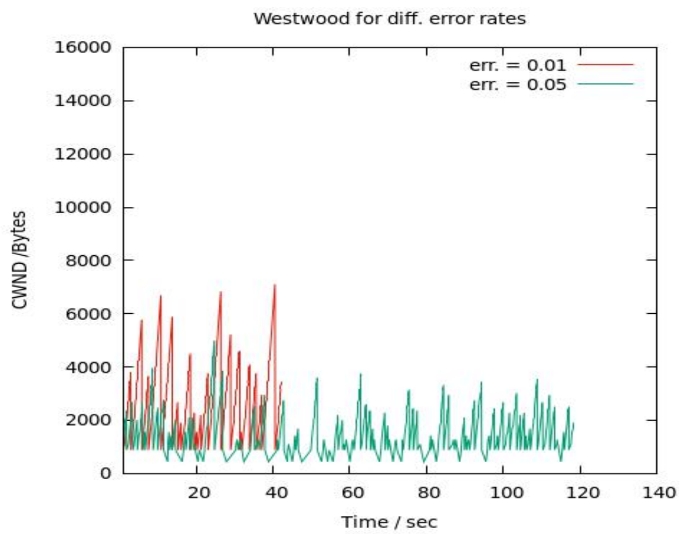

Fig. 2: TCP Westwood for diff. error rates

- packet error rate = 0.01,
- data=1 MB,
- MTU = 500 Bytes,
- BW = 1 Mbps,

Other parameters are defaulted to their values as given in the simulation file.

A. Simulations of WW, WW+, DCM, DCM+

In figures 2 and 3, we show the effect of increasing the packet error rate from 0.01 to 0.05. Westwood fluctuates extremely for all values of error rate. It drops very often to a minimum value of cwnd. Westwood+ is stable for low error rate, but fluctuates less than Westwood for higher error rates. It also shows better performance. Even with higher error rates, it finishes the transmission quicker than Westwood.

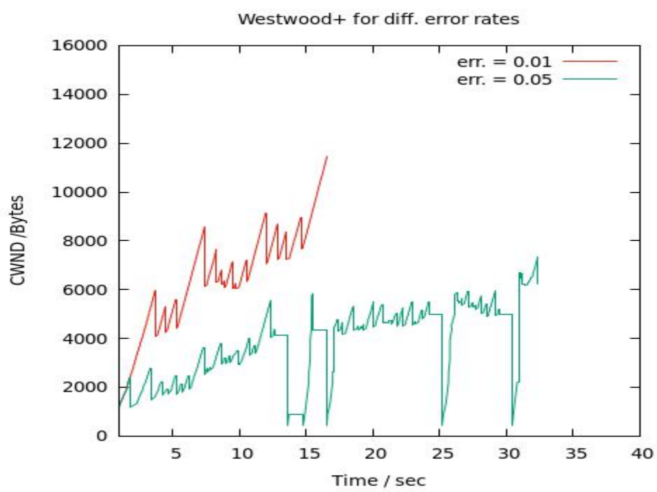

Fig. 3: TCP Westwood+ for diff. error rates

In the next figures, a comparison is shown for RTO and RTT for error rate =0.03 and size of sent data = 1MB. In figure 4, we see, that RTO for Westwood can sometimes exceed the 2msec limit, which is an indication of bad bottleneck. RTO values for Westwood+ never exceed that threshold during the simulation.

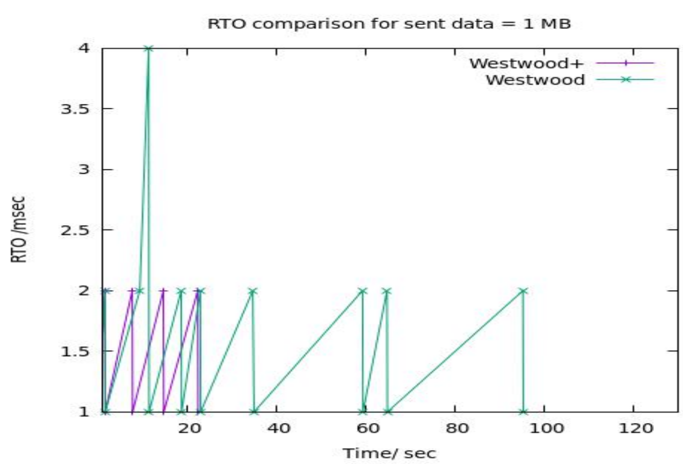

Fig. 4: RTO measurements for WW / WW+

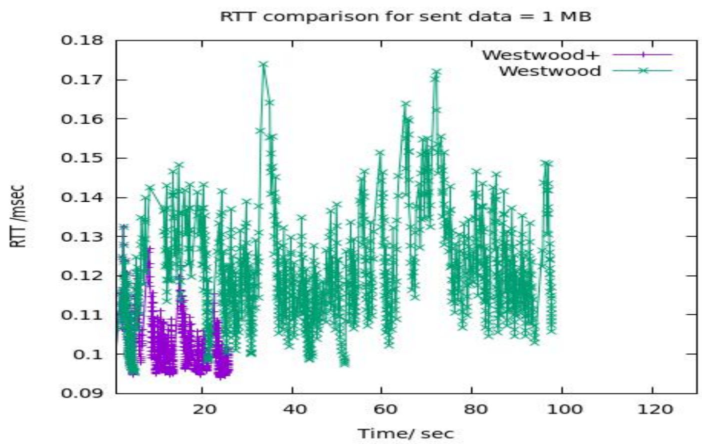

Fig. 5: RTT measurements for WW / WW+

In Fig. 5, the average RTT for Westwood+ is kept minimal as low as 0.10 msec, while it is higher for Westwood, and reaches over 0.175 msec in some cases.

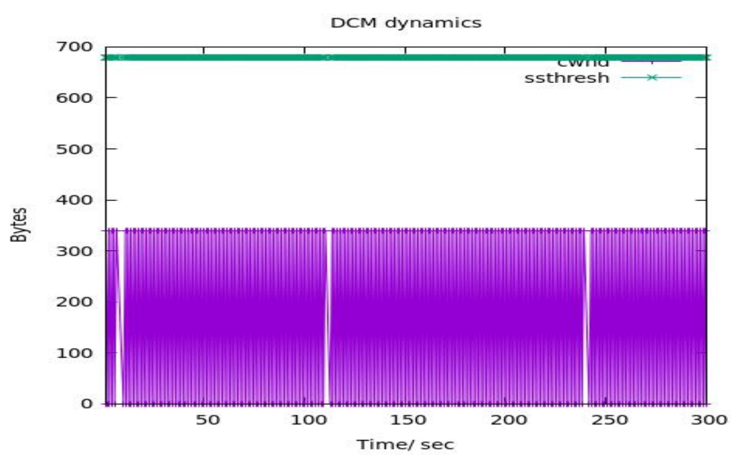

Fig. 6: DCM dynamics

The dynamics of DCM and DCM+ are shown in figures 6 and 7. The simulations are done for error rate = 0.01, and the size of sent data = 10MB. Values of cwnd in Westwood fluctuate around the average value of 170 bytes, but never reaches the maximal ssthresh value (675 bytes).

On the other side, cwnd of DCM+ tracks the actual state of current ssthresh as shown in Fig. 7. It reaches a maximum size of transmission window of nearly 17000 bytes. We measure a huge increase of performance compared with DCM. The comparison of timings between DCM and DCM+ is shown in figures 8 and 9. RTO for DCM+ is always under the threshold (2msec), while for DCM, the threshold is exceeded in many cases. We also see, that RTO for DCM+ can be as low as possible, if no big delay is measured on the link.

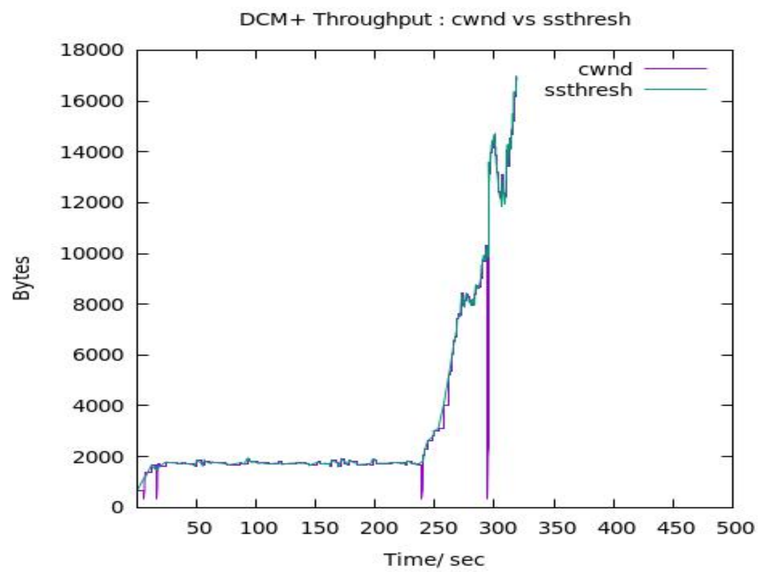

Fig. 7: DCM+ dynamics

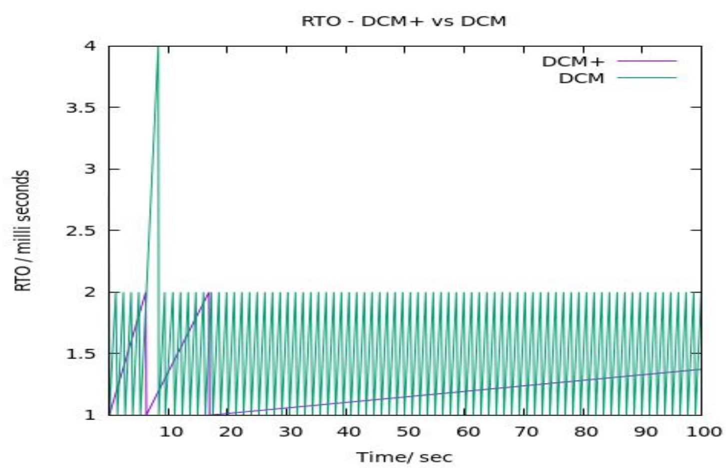

Fig. 8: RTO measurements for DCM / DCM+

RTT measurements for DCM+ are always within the acceptable range (<0.2 msec), but for DCM, it is continuously increasing until 0.29msec, which is higher than allowed, and twice the maximum value of RTT in DCM+. That means continuous congestion generation, which leads to increased instability and fluctuations in DCM.

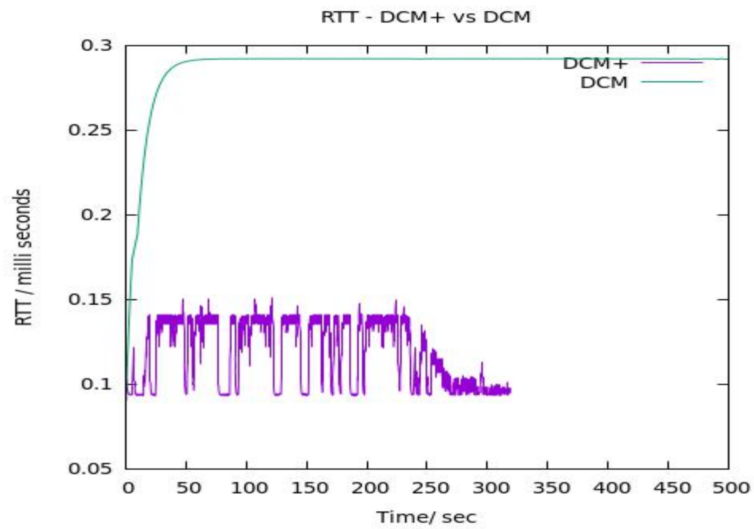

Fig. 9: RTT measurements for DCM / DCM+

DCM+ shows an important property, which is of big benefit in MANETs, especially when path switching is costly. This property is the stability of transmission, and to increase cwnd only if the channel capacity allows that. The Fig. 10 below shows the stability for the parameters below.

The Results show that large MTU value is a helping factor in the stability by using the same error rates and other parameters. This simulation is run for the parameters:

Data size = 10MB, error rate = 0.01 and MTU=1500 Bytes.

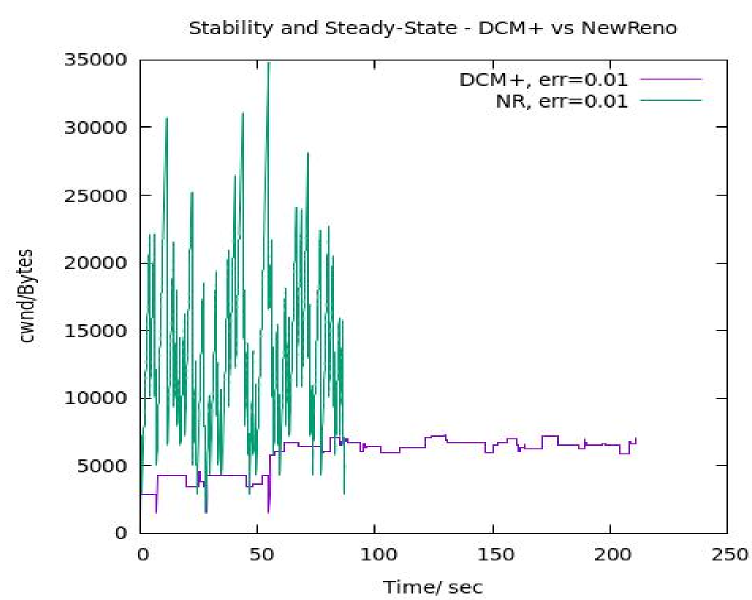

Fig. 10: Stability and Steady-State property in DCM+

B. Statistical Analysis of DCM+

In this section, the results are extracted using *TraceMetrics* and *Wireshark* tools. Plots have been generated using *gnuplot.* We see below the results of the performance metrics like throughput, goodput and delay for DCM+ protocol.

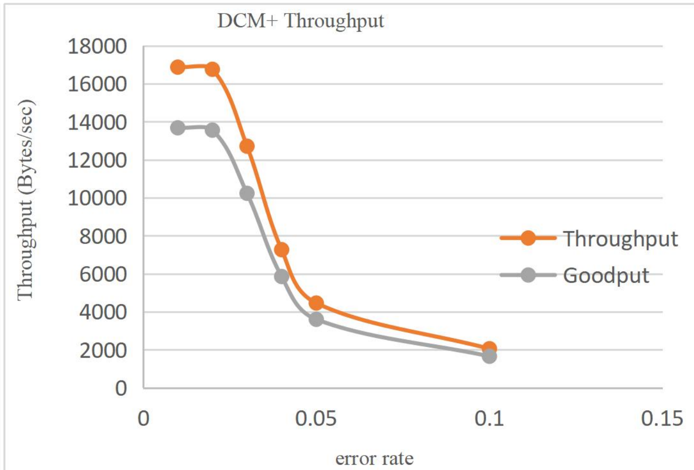

Fig. 11: DCM+ throughput vs. error rate

Below in Fig. 12, we see the reason for instability in DCM+ for large packet error rates. It is the increasing of average delay, which results in low BWE values, and thus low throughput.

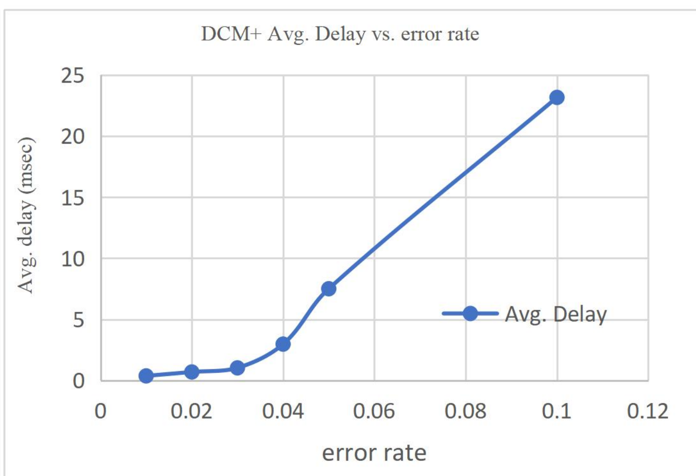

Fig. 12: DCM+ delay vs error rate

VI. CONCLUSION

We proposed a new TCP congestion control protocol, namely DCM+, which has shown excellent performance compared with the DCM version. The simulations are done for a single path topology. The improvements achieved here are according the accurate approach for the estimation of channel capacity like use in TCP Westwood+. Through simulations and analysis, we have shown, that DCM+ owns good throughput and stability. The results depict, that explicit parameters like MTU and error rate can affect the performance. Furthermore, it can be used for different types of networks, namely, wired, wireless and MANETs.

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