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Congestion Control in Wireless Communication with Multiple Radio Interfaces

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***Abstract:** Congestion control is a basic requirement for wireless communication. Number of devices need to communicate using loss-less and lower drop rate paths. Ubiquitous and wireless access to internet was the major step taken by the introduction of Third generation of Mobile cellular network. Still there are some challenges due to different characteristics and prerequisites of wired and wireless network. Important element of Network is Congestion control. Congestion control has to ensure network stability and achieve fair distribution of resources among users of network. TCP is a well-known protocol used in networks for reliable transport and for congestion control. During almost any interaction network is used by users. Network designs using TCP-like congestion control protocols should ensure time bound and successful transaction / communication of data between users. Nowadays, people are concerned about flow completion within minimum time. People are not concerned about network efficiency, network throughput, and packet drop rate or packet delivery ratio. In this paper we represent, various possible approaches used for congestion control in wired and wireless network.*

***Keywords:** Congestion Control, Mobile Interface, TCP, MPTCP, Wireless Communication, Network Layer.*

I. INTRODUCTION

Congestion can be defined as, a situation in communication networks in which a subnet contains a huge number of packets leading to performance degradation. Each network has a higher limit on a number of packets a network can handle. When number of packets send to network is greater than the network capacity congestion occurs.

Consider situation where multiple mobile users exist in a subnet. Each mobile ads to sharing of bandwidth and frequency. Each mobile scans network repeatedly due to congestion in phone devices. Nowadays communication is done through internet for audio and video data, whereas 10years ago it was text and audio. Smartphones need more bandwidth access as data is in the form of video and audio. Congested links become more congested with video streaming and video transfer. Congestion control protocol takes care of long flows. Protocol tries to finish long flow as soon as possible to control the situation of congestion. At the same time protocol behaves fair and stable towards the network [2].

The Internet is in existence from the era of time sharing to current the era of personal computers, client/server and peer-to-peer computing. Computers were considered to be more expensive and rare, but nowadays computers are the medium through which humans can communicate through computer networks as driving force. As computers communicate in a different way than human beings, an approach of communication was shifted from circuit switching to packet switching. The Internet is a collection or network of nodes/devices, where packets share a common path across certain routes. The degree at which traffic from different connection mix is called as the degree of statistical multiplexing [3].

TCP is the first protocol that carried out packet transport and forwarding service [4]. After multiple studies on packet losses and packet control system using TCP and applications, applications found to be more efficient sometimes than the TCP. Some feature of individual packet addressing and forwarding was removed from TCP and the new protocol Internet Protocol was formed to provide those services.

Nowadays devices like mobile, smartphones, laptops, tablets, with multiple wireless interfaces like 4G/LTE, Wifi are more famous[1][5]-[7]. The transport protocols like TCP use one route traversing through only one access interface. This results in wasteful use of a multipath feature of wireless networks [8]. Similar to TCP there are other protocols those were previously tested for congestion control. Some of those protocols are XCP [9], RCP [10, 11], RCP-AC, and TCP Booster.

This paper presents various congestion control algorithms with their advantages and shortcomings. In section II we will see the features of XCP, RCP, RCP-AC, and TCP. Section III introduce with data transmission using multiple paths. A number of algorithms exists for data transmission using multiple paths. List of such algorithms include Parallel TCP (pTCP) [12], Concurrent Transfer Multipath (CMT) over stream control transmission protocol (SCTP) [13], Wireless multipath SCTP (WiMP-SCTP) [14], Westwood SCTP [15], multiple paths TCP (mTCP) [16] and Multipath TCP. Section IV states the conclusion followed by the references. Our aim in this paper is to understand existing congestion control protocols as compared to MPTCP so that performance of MPTCP can be analyzed further more.

II. OTHER ALGORITHMS

a. XCP

Dina Katabi of MIT and Mark Handley of ICIR has developed and published fundamental algorithm of XCP. XCP (Explicit Control Protocol) is a major advance in internet congestion control. XCP is a feedback-based congestion control system. XCP uses direct, explicit and router feedback to avoid congestion in the network while transmitting huge amount of data [17]. XCP is powerful and scalable to the network. XCP can achieve the highest performance on a broad range of network infrastructure. XCP can perform better in the network which includes extremely high speed and very high delay links that are not well served by TCP [17]. By this way, XCP uses maximum bandwidths with no waste of bandwidth and at the same time achieve maximum link utilization. XCP can separate efficiency and fairness policies of congestion control. This separation is Novel by XCP. Routers can utilize available bandwidth for avoiding congestion as XCP takes care of bandwidth utilization. XCP is built upon a principle: carrying per-flow congestion state in packets. The sender can request the desired throughput with the help of congestion header of XCP packets. The sender can learn bottleneck router's allocation by using per-flow bandwidth allocation done by the router. The router does not maintain any per-flow state.

We can calculate bandwidth adjustments for XCP using two algorithms: i) Efficiency Algorithm and ii) Bandwidth calculation algorithm. Efficiency algorithm gives value of bandwidth AB which is distributed to all flows at the interval T and is calculated as,

$$AB = \alpha.(C - ip\_bw) - \beta.\ (q/T) \ldots\ldots\ldots\ldots\ldots\ldots 1$$

where C is the capacity of the link, ip_bw is bandwidth used during last period T calculated on an average RTT, q is minimum queue length, and α and β are performance and stability parameters [18].

Disadvantages of XCP are

- Inherit some unfairness problem of TCP, as it takes many RTT rounds to allocate a fair share to current traffic.
- Cause Many router computation overheads
- More resource and time consuming as to calculate C, it should use the medium at its full for more efficiency of C value.
- Not very good option in large deployments.

b. RCP

RCP (Rate Control Protocol) was proposed by Nandita Dukkipatti. RCP enables large internet flows to complete in one or two orders of magnitude faster than existing TCP and XCP congestion control algorithms. The demand of internet is going to drastically increase in upcoming years with the demand of congestion control mechanism. Congestion control mechanisms are of two types: Explicit feedback from the router to calculate rate and second is per packet calculations for computing rates. Rate provided to flows by anyway remains approximately the same. The router is utilized by RCP to provide the same rate by above methods to all flows. RCP provides excessive bandwidth to the flows for faster completion of flows. RCP achieves this by extreme calculations of excessive bandwidth. Improved congestion control mechanism is achieved by simply emulating processor sharing at each router. RCP assign same rate R(t) to all packets passing through the link. This rate is adapted to current link congestion. Each packet carries a field for the smallest R(t) along the path. If R(t) is found to be smaller, optimum R(t) is calculated at each router and is updated in each packet passing by that router. Destination sends the value back to the source and so, the source can calculate the rate for traffic according to the fair share rate based on current available bandwidth. RCP rate update equation is

$$R(t) = R(t - d_o) + \frac{[\alpha(C - y(t)) - \beta\, q(t)/d_o]}{N(t)} \quad ----(2)$$

Advantages:

- No per-packet computation
- Reduced computation overhead over the routers
- RCP can directly jump to the optimum initialization rate and remains at the optimum rate until network burst is observed.

Disadvantages

- Start with out of date rate i.e. RTT
- Starts faster than TCP and XCP but Run the risk of overshooting (sudden flash crowd and busy traffic conditions where thousands of flows suddenly turn up towards to network, RCP becomes unstable)
- Running overshooting RCP behaves unstable, the fairness of protocols vanishes.

Similarity in RCP and XCP
- At the high-level RCP and XCP behave similarly.
- Assign explicit rates calculated by routers.
- Both algorithms calculate their link capacity which is not right measure in case of not full utilization of resources.

c. TCP
TCP is widely accepted and implemented protocol. Maximum research is done using TCP as it is supported by all simulators and easy equipment configurable. Though it widely experiments, few problems exist with TCP. With dramatically increase in network access speeds in past decades, the standard value of TCP's initial congestion window has remained unchanged [22]. TCP is finding difficulty in coping with the growth of communication network capacities and applications. TCP is not able to properly utilize network links. Delay or packet loss will reduce congestion window of TCP and hence under utilizing links. TCP cannot find the available capacity in the path of flows. Similarly, TCP cannot set the rate of each flow. TCP takes many rounds to find the correct rate for flow. Flows take a longer duration to complete. TCP take a long time to achieve fairness between flows.

d. RCP-AC
RCP-AC is an extended version of RCP developed by same researchers as stated above. RCP-AC is Rate Control Protocol – Acceleration Control. It allows RCP configuration to become quick. This allows completing flows easily in a broad set of operating conditions. It is both, aggressive for FCT to complete soon and conservative for imposing more stability in abrupt situations of the network. RCP-AC protocol was designed with the objective that the protocol behaves stable under the diverged set of traffic conditions.
RCP-AC uses three ways to control traffic in the network: i) Rate Control: sets a target flow rate, like RCP ii) Acceleration control: limits increase in flow rate iii) Feedback control. The priority is given to jump i.e. starting new flows. RCP-AC give priority to limiting queue size if there is congestion. Once per round trip time, these functions are executed in every router. The rcp-ac equation becomes as follow:

$$\Phi = \alpha(C - y(t)).d + (\gamma B - \beta.q(t)) \quad \text{-------------}(3)$$

Where,
φ is the maximum increase in aggregate traffic volume permitted in the next time period
B is Buffer size
γ is a limit on acceleration and is defined by the user
α and β are performance and stability parameters

The rcp-ac equation is near to that of XCP equation. But XCP is not interoperable with current protocols. XCP performance poor if resources are shared with TCP-like flows. RCP-AC is more complex than RCP [19] [20][21].

III. MULTIPLE PATH TRANSMISSION ALGORITHMS

The biggest issue with above list of algorithms is that they are not adaptive to the wireless scenario. Internet was infrastructure dependent and less mobile before. But nowadays with the use of smart mobiles, PDAs, and tablets, the internet is more demanded by wireless devices. TCP's init_cwnd is unchanged since 2002[21], though the global broadband adaptation is increasing with the speed of light. Average TCP bandwidth for any connection is 1.7Mbps, but 70% clients are using the 2G network on their devices.

Above algorithms are heavy to implement in light devices with reference of OS, processing, memory requirement and power consumption. They perform more complex computations which consume more energy, require more memory for storing per packet states. Protocols are heavier for Hot Spot Tathering and might hang on heavy processing. TCP is adaptive to wireless communication, but XCP and RCP are not. TCP has the issues for multimedia flow inclusion [1].

a. MPTCP
TCP uses only one route for transmission of data. This results in wasteful use of a multipath feature of wireless networks. IETF (Internet Engineering Task Force) working group has proposed MPTCP to overcome above problem. MPTCP improves robustness, throughput and resource utilization by dividing data stream into multiple subs flows across multiple paths. MPTCP coexist with plain TCP in a network. This makes efficient use of available capacity from multiple paths and does not degrade the performance of TCP.
MPTCP performance benefits can be achieved by considering following constraints for designing MPTCP.
i) Performance Enhancement: MPTCP should be able to behave as single-path TCP.
ii) Bottleneck Fairness: MPTCP should be able to fairly share bandwidth with single-path TCP on bottleneck link.
iii) Load Balancing: Should move traffic off its most congested paths as much as possible.
Running independent congestion control on each sub-flow will not guarantee fairness across bottleneck link. To be compatible with TCP, a weighted parameter of the regular TCP is assigned to each sub-path. An additive increase function is coupled together with

MPTCP. The parameter controls the value of increase rate for congestion window size. Linked increase algorithm (LIA) uses packet loss as a parameter to carry out load balancing and congestion control. Several performance degradations might be resulted in wireless networks due to the use of packet loss as an indicator. There are two reasons for performance degradation. Firstly, MPTCP algorithms select the path with the lower drop rate. If the selected path is not less congestion path then it results in performance degradation. In wireless networks this is common due to network congestion, and not due to transmission error [23]. Secondly, in the wireless network due to bit errors and handoffs, packet loss occurs. MPTCP congestion algorithms are loss based and assume that an underlying network is reliable [24] [25].

To address above problems and to get more efficiency, following changes were done [26].

i) AN enhanced MPTCP congestion control algorithm mVeno, supporting concurrent multipath transfer.

ii) mVeno algorithm need to investigate suitable weight for different sub-flows of a TCP connection. Similarly, it should achieve following objectives: balance the traffic load distribution among the sub-flows and improve throughput along with fairness preservation on best paths.

iii) Testing mVeno in a test bed and in real WAN for performance validation. Existing MPTCP algorithms can be compared for effectiveness and it shows that mVeno is more effective. mVeno does not loss fairness.

Pingping Dong, Haodong Wang [26] proposed mVeno as a better algorithm for congestion control as compared to other algorithms in MPTCP. These algorithms are extensions to TCP Westwood, TCP Veno, MPTCP-OLIA, etc.

mVeno algorithm is stated below:

Algorithm 1 The mVeno Algorithm

Initialization at $t = 0$
- **for** *each* $r \in R_s$ **do**
  - $\delta_{s,r} = 1/M$;
  - $\beta_{s,r} = 3$;

Upon receiving a new *ack* **on subflow** r**:**
- `/* perform per-round-operations */`
- $T_{s,r} \leftarrow \sum_r sampledRTT_{s,r}/sampledNum_{s,r}$;
- $baseRTT_{s,r} \leftarrow min\{sampledRTT_{s,r}\}$;
- $baseRTT \leftarrow min\{baseRTT_{s,r}\}$;
- $diff_{s,r} \leftarrow cwnd_{s,r} * (T_{s,r} - baseRTT_{s,r})/T_{s,r}$;
- $x_{s,r} \leftarrow cwnd_{s,r}/T_{s,r}$;
- $y_s = \sum_{r \in R_s} x_{s,r}$;
- $T_s = \frac{\sum_{r \in R_s} \text{sampledRTT}_{s,r}}{\sum_{r \in R_s} \text{sampledNum}_{s,r}}$;
- Calculate $E_s[\eta_i]$ and $E_{s,r}[\eta_i]$ according to $Eq.$ (5);
- Linkpara_Adjust();
- `/* perform per-ack-operations */`
- **if** $diff_{s,r} < \beta$ **then**
  - $w_{s,r} \leftarrow w_{s,r} + \delta_{s,r}/w_{s,r}$;
- **else**
  - $w_{s,r} \leftarrow w_{s,r} + \delta_{s,r}/(m * w_{s,r})$;

Linkpara_Adjust():
- **for** *each* $r \in R_s$ **do**
  - $\delta_{s,r} = \frac{P_s(N>\beta)E_{s,r}[\eta_i]T_{s,r}^2 x_{s,r}^2}{P_{s,r}(N>\beta)(1+E_s[\eta_i]T_s^2 y_s^2) - P_s(N>\beta)}$;

CONCLUSION

Considering packet loss as an indicator to achieve load balancing and to undertake congestion control causes performance degradation over wireless communication networks. Existing algorithms consider packet loss as a parameter, so these algorithms lead to performance degradation. A number of algorithms we studied in this paper, like XCP, RCP, TCP, RCP-AC, are performing better in wired networks, but are not better congestion controllers for wireless networks. To address this issue number of algorithms were designed for wireless networks, like MPTCP, Parallel TCP (pTCP), Concurrent Transfer Multipath over stream control transmission protocol (SCTP), Wireless multipath SCTP (WiMP-SCTP), Westwood SCTP, Multiple paths TCP (mTCP) and Multipath TCP. We studied MPTCP as one of an algorithm for concurrent multipath transfer. mVeno refines Veno's additive increase algorithm by assigning different weighted parameters for different paths to couple all the sub-flows of a TCP connection. A fluid model of mVeno is enveloped and can be used to derive weighted parameter with MPTCP constraints satisfaction. The results of extensive testbed experiments and real WAN environment demonstrate that mVeno is an outperformer. Future work can be pointed towards a balance between power consumption and use of multiple paths for mobile devices in wireless networks.

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