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AQM과 ECN을 사용한 TCP 변종의 성능 분석

Performance Analysis of TCP Variants using AQM and ECN

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요 약 전송계층 프로토콜처럼 전송제어 프로토콜은 안정적인 데이터 전송 서비스를 제공한다. 다양한 네트워크에서 TCP의 성능을 저해하는 일부 심각한 문제가 있다. TCP 네트워크 환경에서 중요한 문제는 빠른 전송 속도로 인해 또는 동시에 네트워크로 접속하는 다수의 새로운 접속으로 인하여 발생하는 혼잡이다. 그러므로 라우터에서 큐의 크기는 패킷 하락에 기인하여 증가한다. 손실된 패킷의 재전송과 감소된 처리량은 많은 비용을 발생시킨다. RED처럼 AQM과 ECN은 패킷 하락 보다는 패킷 마킹에 사용된다. IP 패킷 헤더에서 ECN 비트는 불필요한 패킷 하락을 피하기 위한 혼잡 표시로 추가할 수 있다. 제안하는 ECN과 AQM 메커니즘은 NS2 시뮬레이터의 도움으로 구현할 수 있으며, 그 성능은 다른 TCP 변종에서 테스트할 수 있다.

Abstract Transmission Control Protocol as a transport layer protocol provides steady data transfer service. There are some serious concerns about the performance of TCP over diverse networks. The vital concern in TCP network environment is congestion which may occur due to quick transmission rates or because of large number of new connections entering the network at the same time. Size of queues in routers grows thus resulting in packet drops. Retransmission of the dropped packets, and reduced throughput can prove costly. Explicit Congestion Notification (ECN) in conjunction with Active Queue Management mechanisms (AQM) such as Random early detection (RED) is used for packet marking rather than dropping. In IP packet header ECN bits can be added as a sign of congestion thus avoiding needless packet drops. The proposed ECN and AQM mechanism can be implemented with help of ns2 simulator and the performance can be tested on different TCP variants.

Key Words : Acknowledgement, Transmission Control Protocol (TCP), Explicit Congestion Notification (ECN), Queue Management Mechanisms (AQM), Random Early Detection (RED)

Ⅰ. Introduction

TCP is a connection oriented protocol that provides flow control, error control and reliable packet transmission service. TCP faces network congestion problem that occurs when a link is transmitting so abundant data that its quality of service drops that results in queueing delays and packet losses. Due to Congestion packets can be missing, repeated, or transmitted out of order. There are some variants of TCP which are used to minimize congestion in a network [1].

Congestion control mechanism in TCP plays an important role in internet and different applications. It

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controls the amount of traffic injected in a network and handles overall performance of the communication. Congestion occurs when demand of resources is greater than supply. In this case packet drop occurs and retransmission is required. Due to separate layers routers cannot inform TCP about congestion. Routers operate at the network layer and therefore do not interact with the transport layer. This sustains the layered structure of the TCP/IP suite as every layer has certain function. Congestion can be detected by the loss of a packet which is indicated by duplicate ACKs or when an ACK is not received within a time frame (RTO). Slow Start (SS), Congestion Avoidance (CA), Fast Retransmit and Fast Recovery are the algorithms that impose congestion control [2].

Active Queue Management (AQM) can execute special program inside router when congestion is occurred. AQM apply congestion control through transmission path of packet. Random Early Detection (RED) is used for measurement of traffic load among AQM process. RED is used to detect congestion in packet switching network. Average queue length is checked in RED to discard a control packet, which is calculated by probability when length of queue is exceeded threshold. RED algorithm compares maximum threshold and minimum threshold. RED policy is if average queue length is greater than min threshold, RED has normal condition and if average queue length is greater than min threshold and is less than max threshold, input packets is randomly discarded. And finally if average queue length is greater than max threshold, all of input packets are discarded [3].

II. Related Work

Congestion solutions are possible by applying Queue management schemes at routers while at the end points congestion avoidance schemes can be used in networks. AQM (Active Queue Management) techniques provide congestion free data among peers to increase the performance of network. Active Queue Management algorithm provides early congestion notification to avoid packet losses. Feedback dynamic system can be used for the TCP connections through the congested routers. And in order to analyze the network behavior, control theory-based approaches can be used to adjust AQM's parameter settings, and design new AQM schemes. Control system based analysis provides new understanding into AQM design [4].

In Internet routers, Active Queue Management (AQM) is a technique that drop packets and Explicit Congestion Notification (ECN) marks packets before a router's queues are full. Internet router manages a set of queues per interface that hold packets to go on that interface. These queue use drop tail algorithm in which a packet is put on the queue if the queue length is shorter than its maximum size which is measured in packets and dropped otherwise. AQM drop or mark packets before the queue becomes full. AQM calculates drop/mark probabilities, and on the basis of probability it drops or marks packets even when the queue is short. This approach is unique as it uses dynamic model of the transmission control protocol (TCP) which enables application about control principal to solve the basic feedback nature of AQM [5].

ECN is used in combination with Active Queue Management (AQM) policy. The advantages of ECN depend on the selection of accurate AQM. Active queue management (AQM) is the random reorder or drop of network packets inside a transmit buffer which is related with a network interface controller (NIC). Router handles a set of queues one per interface to handle the packets of that interface. Internet provides best effort service, the network does it's best to deliver the data as efficiently as possible. ECN capable routers have the capability to mark packets to indicate congestion. Marking the packets means changing a bit in the packet header which ranges from zero to one to indicate congestion [6]. Each receiver echoes the marks to its source and the source is expected to respond to each mark by reducing its transmission rate.

Protocols ability and strength is the key to internet success. Most applications currently in internet depends on TCP/IP protocol. TCP/IP has the ability to serve in high traffic times. The main reason for this was TCP congestion control. TCP congestion control handles the network load by transmitter nodes which regulate their transmission speed by virtue of the congestion rate in the network.It allows TCP to search for additional bandwidth such conduct leads to lose the packet. Upon receiving three repetitive feedbacks for each sent packet, it finds a lost packet and the window size decreases to one and threshold to half to prevent the congestion. If all packets are delivered then TCP source increases slowly the packet sending rate to use the speed network capacity [7].

The routers are too slow to perform different task like queuing buffers, updating tables etc and the routers buffer is too limited. Congestion can also occur due to slow speed CPU which are responsible for queues built up at routers. Congestion can also occur due to slow links. Similarly high speed links can also create problems by making network unbalanced. The use of ECN for notification of congestion to the end points avoids needless packet drops. ECN is deployed for congestion notification to prevent packet drops. By ECN gateways can mark the packet instead of discarding them. Therefore the source node can take proper action by slowing down their data transmission rate [8].

Explicit Congestion Notification (ECN) uses packet marking technique for routers as indication of congestion instead of packet dropping. In this way router inform TCP peers about the congestion in the network. In reply TCP peers avoid packet losses by slowing their data transmission rates. ECN threshold is set in order to improve TCP throughput performance. At router the value of queue length is checked against threshold value. When this value becomes greater or equal to threshold value the packet is marked with congestion experienced bit and the receiver sets a flag in the Acknowledgment header to indicate congestion. As a reaction sender cuts down its congestion window to avoid congestion [9].

Ⅲ. TCP AND ITS FLAVORS

Transmission Control Protocol (TCP) is one of the 4 layers in the TCP/IP reference model which connects to the network that allows the IP packets to process the streams of data using the route table. Different variants of TCP show varying behavior in best effort Internet Protocol networks. Here are some of the TCP Flavors.

1. TCP Reno

After packet loss the probability of duplicate acknowledgement increases, there is chance that the packet may be pending in the long flow between sender and receiver. This problem is solved by TCP-Reno where there are three duplicated ACKs about the same packet means that the packet is lost or not received, the congestion window size is decreased to half. TCP-Reno introduced a new algorithm “Fast Retransmit” which retransmits the packet without time out to occur. In the last state called Fast Recovery, if three duplicate acknowledgements received the packet was retransmitted and again waiting for the ACK. This ACK is the acknowledgment of the all previous packet received and what is the next packet to be sent to receiver. It is also a chance that no ack will be received before timeout then TCP-Reno take into slow start.

2. TCP New Reno

TCP New Reno is the modified version of TCP Reno. It has the improvement of resource utilization to finest. Congestion window starts with segment one, it is consistent but ultimately negotiating with performance. Sender doesn’t wait for timer to timeout for igniting for retransmission.

3. SACK TCP

SACK TCP is presented to improve throughput which has been affected when multiple packets are lost from one window of data. TCP senders can only learn about a single lost packet per round trip time (RTT). SACK mechanism can be used by sending back SACK packets to the sender acknowledging the recipient of the data to improve the performance. The sender only need to retransmit the missing data segments instead of sending packets that have already been received. For each packet loss detection in New Reno takes one RTT. Therefore selective acknowledgment (SACK) was proposed. It is an extension of TCP Reno and TCP New Reno. It solves two problems of TCP Reno and New Reno e.g Packet loss detection and retransmission of lost packets per RTT. A variable “pipe” can be introduced that can calculate missing packets. If missing packets found, it reduces the size of congestion window [10].

그림 1. IP 헤더
Fig. 1. IP Header

ECN mechanism can be explained with diagrams.

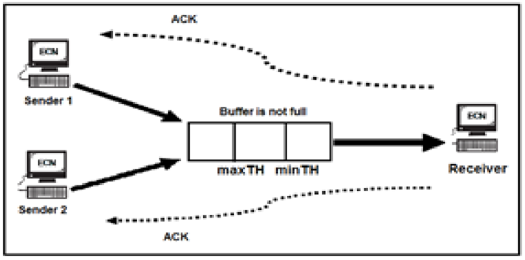

그림 2. ECN 정상 프로세스
Fig. 2. ECN Normal Process

4. TCP Vegas

Vegas utilizes a bandwidth estimation scheme to forecast congestion on the network. It does not rely on packet loss as an indication of congestion. To calculate available bandwidth, it calculates the difference between the expected rate and the actual rate. TCP Vegas detects congestion that occurs between endpoints before packet loss happen and lower its transmission rate linearly which is different from AIMD.

Ⅳ. Mechanisms of ECN

The ECN scheme works by having the routers mark Congestion Experienced (CE) bit in the IP packets. It is based on the probability (Above max TH – mark all packets, between min TH and max TH – mark packets based on probability) derived from the average queue length. The sender trigger the congestion avoidance algorithm when the Router will mark the CE bit in the packet which will notify the sender through ACK by the receiver of the developing congestion. Upon activation of congestion avoidance algorithm the sender will set the CWR (Congestion Window Reduced) bit on the next outgoing TCP packet to signal to the receiver that it has taken the necessary action. When receiver receives CWR, it will halt the sending of congestion notifications (ECE) to the sender if there is no new congestion in the network [11].

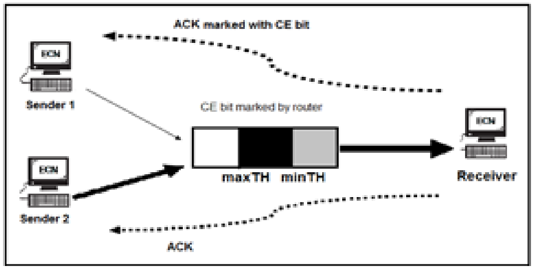

그림 3. 패킷 마킹
Fig. 3. Packet Marking

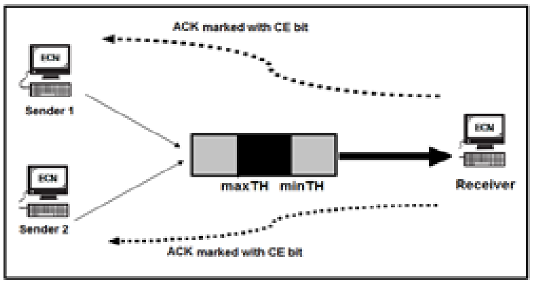

그림 4. 최대 임계 값
Fig. 4. Maximum Threshold Reached

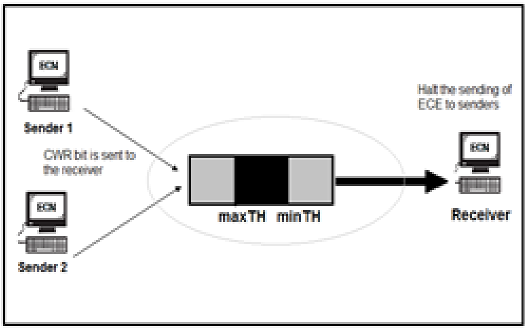

그림 5. CE의 인식
Fig. 5. Acknowledgement of CE

Packets are sent from senders to receiver as buffer is not full so normal process continue.

Minimum threshold is reached and packets are marked based on probability. Sender 1's ACK is marked with CE bit to notify it to initiate congestion control, therefore the sender reduce its transmission rate as indicated by the thickness of the arrow.

Maximum threshold is reached and all packets are marked. Packets from both senders are marked with CE bits to notify them to initiate congestion control, therefore both their transmission rates are reduced.

Ⅴ. Proposed Approach

1. Methodology

The objective of this set of experiments is to determine the performance gain from implementing ECN where packets are marked instead of being dropped during network congestion. This simulation will compare the performance of ECN-enabled TCP against non ECN capable TCP operating in a RED-based network. The Dumb-bell topology will be used in this experiment whereby the setup for the simulations will be exactly the same. The only difference is to enable the marking of packet with a congestion bit for the ECN-enabled network instead of dropping it. The parameters will be used when implementing the OTcl scripts in NS-2.

2. Simulation Diagram

The experiment used a buffer size of 20 packets on the router operating on a 100 Mbps bandwidth and 10 ms delay. File Transfer Protocol (FTP) will be the sending agent that will transmit packet from 3 senders to 3 receivers. The packet size will be set at 100 bytes. The minimum and maximum threshold for the ECN and RED network will be set at 5 and 15 respectively.

Network collapse can occur without proper congestion control mechanisms as there is the possibility of inadequate useof resources. Performance of a network can be adjusted according to the changes in the traffic load. Congestion control requires swift measures at both endpoints and at the routers[12].We can evaluate the results obtained from implementing the various sets of experiments. Each set of experiments consists of different simulation scripts that were implemented with different queuing schemes, packet sizes and threshold parameter settings. The events that took place during each simulation were recorded into a trace file which was Post-processed using Perl script. Subsequently, Microsoft Excel was utilized to convert the readings into graphs and charts for evaluation.

Figure 8.0 further demonstrates lower packet drop rate for ECN compared to RED and Tail Drop which does not regulate transmission rate. As such, the constant flow of packets into the buffer will increase the occurrences of packets being discarded as opposed to ECN mechanism that notifies the TCP senders to trim their transmission rate.

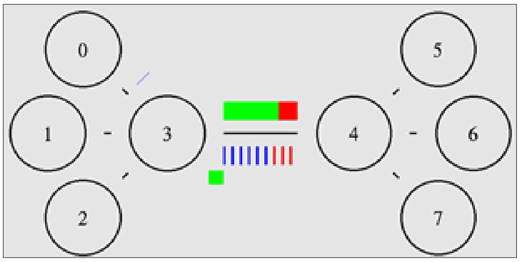

그림 6. 시뮬레이션 다이어그램
Fig. 6. Simulation Diagram

표 1. 매개 변수
Table 1. Parameters

Parameter name		Description		Values	
Bottleneck Link	Bandwidth	Bottleneck link Bandwidth		1 MB/S	
	Delay	Bottleneck link delay		10 ms	
ECN	Ecn	Enabled	Disabled	Set bit_ true	Set bit_false
Link	Bandwidth	Link bandwidth		100 Mb/s	
	Delay	Link delay		1 ms	
RED	minth	Minimum threshold		5	
	maxth	Maximum threshold		15	
	q_weight	Smoothing factor		0.0002	
	queue-limit	Queue size		20 packets	

표 2. ECN 없는 경우
Table 2. Without ECN (Packet Size=200)

TCP Variants	Total Packets Received	Total Packets Dropped	Average Queue Length	Overall Throughput in bits per second	Average Throughput (Mbps)
Reno	3757320	7920	28.9	300585600	100.19
Newreno	3752040	8400	25.1	300163200	100.05
Sack	3757320	5760	23	300585600	100.19
Vegas	3729600	0	6	298368000	99.45

표 3. ECN 효과가 있는 경우
Table 3. With ECN Effect

TCP Variants	Total Packets Received	Total Packets Dropped	Average Queue Length	Overall Throughput in bits per second	Average Throughput (Mbps)
Reno	3752040	1920	28	300163200	100.05
New Reno	3751800	3120	26.4	300144000	100.04
Sack	3752040	2640	26.3	300163200	100.05
Vegas	3729600	0	6	298368000	99.45

표 4. 수신한 패킷, 하락한 패킷, 평균 처리량
Table 4. Packet Received, Dropped, Average Throughput

TCP Variants	Total Packets Received	Total Packets Dropped	Average Queue Length	Overall Throughput in bits per second	Average Throughput (Mbps)
Reno	3777640	73840	8.5	302211200	100.7
New Reno	3850440	78000	6.8	308035200	102.6
Sack	3275320	61360	5.2	262025600	87.3
Vegas	3766000	1000	7	301280000	100.4

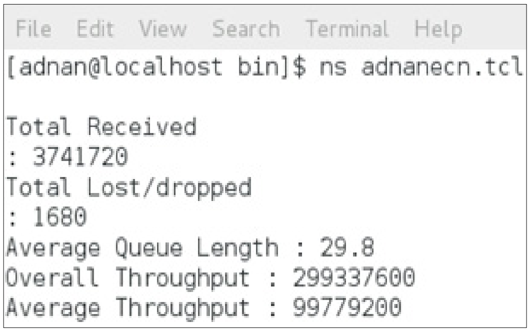

그림 7. NS-2에서 계산된 처리량
Fig. 7. Throughput calculated in NS2

In this instance, although ECN cannot totally eliminate packet drop and retransmission, it has reduced it. It has been noted in Figure 9.0 that ECN. has a higher average queue length than RED, but this is due to the higher percentage of packet drop for RED which translate into shorter queue length.

Figure 10 demonstrates the performance difference between TCP variants as it New Reno has better average throughput of 102.6 Mbps compared to others. This translates into better effective use of the bandwidth and lower packet drop.

V. Future Work

The implementation of ECN would need to be supported by the appropriate buffer size and network parameters, otherwise ECN would not be able to realize its full potential. Some more variants can be evaluated in future. Threshold setting and buffer size also play a critical role in ensuring better throughput, shorter queue length and lower packet drop rate in future. To fully utilize the potential of ECN and RED, the buffer would need to be of an appropriate size that is proportional to the traffic the network is expected to handle. However, this set of experiments does not involve the changing of buffer size or bandwidth but in future it can be done.

VII. CONCLUSION

From the results obtained from the experiments, we can conclude that ECN helps to regulate transmission rate by notifying the TCP endpoints to activate congestion avoidance once it detects impending congestion. As such, good put increases as the occurrences of packets being dropped and retransmitted is minimized.

This paper has achieved its aims: to evaluate the performance of TCP Explicit Congestion Notification under AQM like Random Early Detection Parameterization Tuning. The paper was started with little understanding of Active Queue Management and the network simulator. The first goal was to gain a basic understanding of the network architecture, the various Flavors of TCP and the different types of passive and pro-active congestion control algorithms that have been introduced to improve the efficiency of TCP.

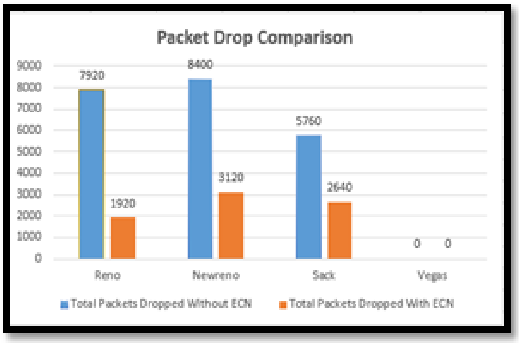

그림 8. 시뮬레이션 다이어그램
Fig. 8. Simulation Diagram

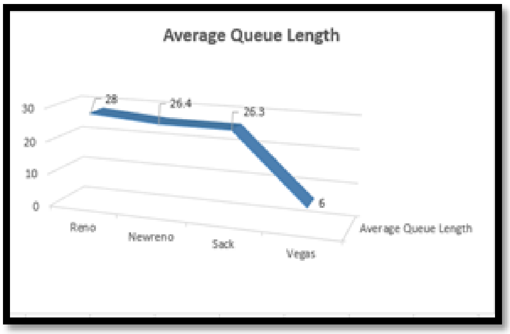

그림 9. 평균 큐 길이
Fig. 9. Average Queue Length

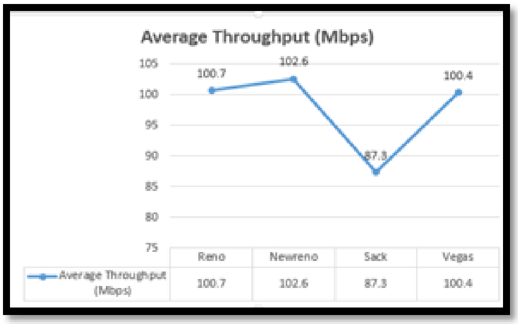

그림 10. 평균 처리량
Fig. 10. Average Throughput

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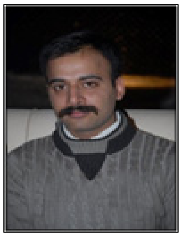

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