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A survey on congestion control techniques in AD-HOC network

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ABSTRACT

Identifying the occurrence of congestion in a Mobile Ad-hoc Network is a major task. The existing TCP congestion control techniques do not handle the unique properties of shared wireless multi-hop link. Frequent changes in the ad-hoc network topology poses great deal of problems for congestion control. There are several approaches proposed for detecting and overcoming the congestion in the mobile ad-hoc network. In this paper we try to bring out some of the congestion control techniques and its salient features.

Introduction

In this paper we discuss about congestion control in Mobile Ad-hoc Network (MANET). In the present scenario the mobile communication takes place with ISO frame format 802.11 in ad-hoc mode using Base Station (BS) and Backbone Networks (BN) such as Wireless Local Area Network (WLAN), WiFi , 3G, 4G etc.,. Mobile Ad-hoc Networks do not have a fixed infrastructure.

In ad-hoc network each node (Mobile device) acts as a router, which helps in forwarding packets from a source to destination. MANET are suitable in situations where fixed infrastructure is unavailable such as Military war fields, disaster relief, sensor networks, Wireless mesh network etc., share some of the congestion control related issues with ad-hoc network.

A lot of research is being carried out in MANET area in regard to congestion control, routing of packets, modification of standard TCP protocol, designing of new routing protocol, etc.,. The standard TCP designed for general network and Internet, can not handle specific problems occurring in MANET.

In a network many devices sharing a common resource compete for link bandwidth, which leads to network overload. To avoid network overload each sender has to adjust its data sending rate. When more data packet arrives at the router, the un-serviced packet gets dropped. These dropped packets would have consumed most of the network resources. The lost packets have to be retransmitted, which in turn leads to pumping of more packets into the network, resulting in degradation of network throughput (congestion).

A proper mechanism is to be adopted to avoid congestion collapse of the network, this lead to the development of TCP congestion mechanism [1]. In OSI reference model, congestion control is the responsibility of the transport layer. The combination of congestion control and reliability features in TCP, allows performing congestion control management without the information about congestion status of the network.

TCP does not require any information about the congestion status of the intermediate node. To detect network congestion TCP monitors the occurrence of packet loss. In Internet packet loss (missing packets) is considered as network congestion.

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Related work

A suitable congestion control technique for MANET is considered as an important issue. Some of the congestion related issues like throughput degradation and flow fairness are initiated from Media Access Control (MAC), routing and transport layer as discussed in [2][3][4][5]. Several papers have addressed these problems and provided suitable solutions to overcome these problems.

A. Congestion in MANET.

TCP congestion control is very much suitable for Internet, where as for MANET the same TCP is not suitable due to some of the specific properties like node mobility and shared wireless multi-hop channel. A slow delivery and packet loss occurs due to node mobility and unreliable shared medium. The delay in the packet delivery or packet losses may be due to route change should not be misread as congestion.

In Internet when congestion occurs it is normally concentrated on a single router, where as, due to the shared medium of the MANET congestion will not overload the mobile nodes but has an effect on the entire coverage area. The change in the routing of the packet might lead to packet losses which is not caused due to congestion in the network should not be erroneously misinterpreted as TCP congestion. This can lead to wrong reactions of TCP congestion control. Furthermore, monitoring packet losses is much harder, because of their transmission times, round trip times also vary.

Due to low bandwidth of MANET, a single node can cause collapse of entire network accidentally. Thus the effect of single traffic flow may cause major unfairness in flow control. Furthermore multi-hop network is prone to overload related problems than wired networks. Hence a suitable congestion control for a MANET is necessary for a stable network and satisfactory performance.

B. The approaches for congestion control in MANET

The most important problems and approaches that are known in MANET congestion control research so far are listed below.

- Route failure.
- TCP Acknowledgement scheme. Unfairness between TCP flows induced by shared

- TCP traffic is Bursty.
- Wireless link losses.
- New Protocols for MANET

Route failure

The most important approaches that are known in MANET congestion control research in route failure problem are listed in Table 1.

TCP – Feedback (TCP-F)

In 1998 Chandran et al. proposed a TCP – Feedback (TCP-F) approach to tackle the problem of congestion control mechanism in MANET. In the event of packet losses due to non congestion and time out condition because of route failure, first this technique disables the congestion control mechanism of TCP.

TCP-F generates two messages, Route Failure Notification (RFN) and Route Re-establishment Notification (RRN), when route failure occurs and a new route is found. After receiving RFN message and a new route to destination node is not available, the sender goes to sleep state by freezing the timer and the window size. When the intermediate node detects link failure on the route, immediately it sends RFN message to the sender. Upon discovering a new route to the destination the intermediate node sends RRN message to the sender. After receiving RRN message the sender restarts TCP session with the frozen state values (timer and window size). An additional timeout is used in case of RRN message is lost, to avoid TCP – F sender going into sleep state for ever.

Explicit Link Failure Notification (ELFN)

Holland and Vaidya analyzed the effect of Explicit Link Failure Notification (ELFN) techniques on TCP performance. ELFN sends feedback from lower layers to inform TCP about link or route failures. In case of such a failure, the sender enters standby mode, which is same as that of TCP-F's sleep state. Where as, no specific notification is sent in case of a new route is found. As an alternative, a TCP-ELFN sender sends probe packets in regular intervals when in standby mode. No special control packet is used in ELFN route failure notifications. The authors intend to either piggyback the notification message or to use an ICMP for a route failure message sent by the routing protocol or host unreachable message.

TCP with Buffering capability and Sequence information (TCP-BuS)

The clear notifications from the transport layer are extended by augmenting TCP layer. This was proposed by kim,Toh and choi in TCP-BuS. In case of route failure the intermediate nodes buffer the packets instead of discarding them. The purpose of buffering packets is to avoid retransmission of lost packets. The timeout for these packets are extended and the buffered packets are delivered.

Some of the lost packets requested by the destination node are sent without waiting for extended timeout to expire, thereby helps in faster recovery.

Enhanced Inter-layer Communication and control (ENIC)

This technique is proposed by Sun and Man. In this technique TCP's selective acknowledgment (SACK) and delayed acknowledgment (DACK) mechanisms are combined with route failure as in ELFN. ENIC requires less support from the intermediate nodes in comparison with TCP-BuS. In case of route failure or recovered route no explicit notification is sent like in ELFN, instead it reuses existing messages generated by routing protocol. When route failure occurs the packets in the queue are dropped. This technique does not support the buffering of packets at intermediate nodes like in TCP-Bus.

In ENIC, both sender and receiver are notified when route failure occurs. This calculates a new timeout, Temporary Retransmission Time Out (TRTO) value after the route change. This is based on hop count of old and new route.

TCP-ReComputation (TCP-RC)

This technique was proposed by Zhou et al. which mainly concentrates on the characteristics of new route after route reestablishment. It extends ELFN technique to recalculate TCP's congestion window size and slow start threshold value based on the characteristics of new route. It uses round trip time and route length to find new values for slow start threshold and congestion window size

TCP for mobile ad hoc networks (ATCP)

ATCP is a solution proposed by Liu et al. for some of the TCP congestion related problems in MANET's. This technique not only deals with route failure, it has a special capability to correctly mange long time disconnection in the route. It distinguishes correctly between congestion related and other losses, thus sending explicit congestion notification (ECN) messages. In case of non congestion losses ATCP uses TCP state freezing technique similar to ELFN probe packet mechanism instead of using standard TCP congestion control mechanism. If ECN messages are not received, the lost packets are treated as non congestion related. To implement this technique an additional layer is introduced below transport layer to reduce frequent interaction with TCP.

Preemptive routing

Goff et al. proposed a new solution called preemptive routing, which unearths a new route in anticipation of route failure. This overcomes longer disconnection times. In this technique along a path each node measures the signal strength upon receiving a packet. If signal strength is below certain threshold value a warning message is sent to source node, to lessen the small scale fading. The exponential average or verification of measurement is carried out by sending small ping – pong packet along an established link.

TCP Acknowledgement scheme

It is known that packets are transmitted in shared medium, which results in packets are transmitted in the same route or spatially close routes or in the opposite directions severely affects each other due to shared medium. This section mainly addresses the acknowledgement (ACK) traffic. The approaches are listed in Table 2.

Dynamic delayed ACK

This technique was proposed by Altman and Jim´enez. In Dynamic delayed ACK technique, an acknowledgement packet is sent only after n number of segments or after a certain fixed timeout. As claimed by the author if $n = 2$, there will be a significant performance improvement. However if the TCP window size is small, the technique may not perform as expected, therefore it is proposed that using Dynamic delayed ACK with an increase in packet sequence number the value of n increases up-to 4. After reaching this limit, the value of n is never decremented. It is suggested that if the value of n is equal to current window size then better results are expected.

Dynamic adaptive ACK

This technique was developed by De Oliveira & Braun, it uses the concepts of TCP congestion control [RFC 2581] to MANET's. It calculates dynamic acknowledgement timeout based on packet inter arrival time at the receiver. An immediate acknowledgement is initiated when an out-of-order packet arrives at the receiver. The author claims that, before timeout occurs it is advisable to wait until next packet in the sequence arrives. If the received packet is in order the timer resets, otherwise it initiates an immediate acknowledgement. Added to this mechanism, it also uses technique adopted by Dynamic delayed ACK.

Preferred ACK Retransmission

The Preferred ACK Retransmission technique is proposed by Sugano et al., to handle acknowledgement traffic. It uses both ELFN messages and DACK option for TCP on commercially available MANET called Flexible Radio Network (FRN). The implementation is not based on IEEE 802.11 standards, but uses fixed time slot on the medium. It is claimed that, by implementing this features it reduces repeated collision of data packet with that of ACK packet in the same stream. In this technique the ACK packets are given high priority than that of data packet by reducing MAC retransmission interval.

Combining data and ACK packets

This technique is designed for FRN by Yuki et al., uses same frame for TCP Data and ACK packets. The basic idea behind combining Data and ACK packets is to avoid underutilization of FRN time slot for small ACK frame. This helps in reducing collision between Data and ACK packets, if the queue of transmitting node contains both these packets. The author claims that this technique is also well suited for generic MANET, but supporting experimentation results are not given other than FRN.

Unfairness between TCP flows induced by shared medium.

In an ad-hoc wireless network all the nodes share a common medium for communication in a coverage area. To carry out congestion control in ad-hoc wireless networks, it poses a great deal of challenge. This challenge lies in the coverage area rather than in individual nodes. In this area, several works has been carried out to address these problems. Some of these techniques are listed in Table 3. Theses techniques are discussed briefly in this section.

LRED / adaptive pacing

In wired network the Random Early Detection (RED) [38] technique, the packets are dropped linearly in the router queue as the queue length increases. The RED mechanism normalizes the bandwidth requirements of TCP flow along the router, before congestion occurs.

Fu et al., proposed two techniques - Link RED (LRED) and Adapting pacing approach to address the best possible way of altering the TCP window size by predicting early reaction to the link overload. The possibility of packet being dropped is monitored based on the required number of transmissions of the MAC layer. This technique is initiated when a specific threshold is reached. If the possibility of packets being dropped is increased after regular retries, it is inferred as congestion in the link.

Adaptive pacing approach is initiated, when retransmission count of LRED exceeds the threshold value. The technique augments the senders MAC back-off timer with packet transmission time, to avoid well known exposed receiver problem, when it is enabled.

Neighborhood RED (NRED)

Xu et al. proposed NRED, where all nodes in wireless ad-hoc network participate in estimating the packets queued in neighboring nodes, thus forming a virtual, distributed neighborhood queues. If virtual queue length goes beyond a threshold value, the possibility of packets being dropped increases leading to congestion in the network.

NRED performs action in three phases. In the initial phase it estimates the neighborhood queue size by analyzing the utilization of the channel. It is presumed that the neighborhood is likely to get congested, if channel utilization exceeds the threshold value. In the second phase it computes the probability of packet drop. This information is shared with the neighboring nodes. Furthermore, in the last phase each node computes its packet drop probability based on the information received. Based on the drop probability information, the incoming packets are dropped, similar to RED, in virtual neighborhood queue.

COntention-based PAth Selection (COPAS)

C de Cordeiro et al. proposed COntention-based PAth Selection (COPAS) mechanism, which mainly addresses the capture problem of TCP in MANET's. The nodes illegally capture the medium compared to others in the network. COPAS, is an extension for reactive routing protocol. All the routes between source and destination are collected in the course of route discovery. The TCP and ACK traffic are sent on disjoint routes, to avoid effect of both capturing the medium. The decision of path selection is based on congestion measurements carried out during the process of route discovery. The measurement always depends on backoff times for each node. During route discovery these measurements are updated continuously so that, too congested routes are replaced with that of best route.

Congestion Aware Routing (CAR)

Ye et al. proposed Congestion Aware Routing (CAR). This approach modifies routing based on the distributed congestion information, to separate TCP flows spatially.

In this approach the author has proposed two solutions, centralized CAR (CCAR) and distributed (DCAR). In centralized approach, every node is assumed to be updated with the information about the source, destination and the route of each TCP flow. In distributed approach every node, depending on the load condition, computes a congestion weight. This information is shared with its neighboring nodes.

A modified Ad-hoc On-Demand Distance Vector (AODV) routing is adopted for route discovery. Both these approaches surpass the shortest path routing protocol in terms of throughput for longer paths. The centralized approach performs better than distributed approach and is preferred for shortest path, when distributed approach fails. It is observed by the author that, the performance of DCAR, compared to that of CCAR is poorer due to outdated congestion information.

Split TCP

In Split TCP, a completely different technique to solve TCP congestion problem in MANET is proposed by Kopparty et al. In this technique, end to end reliability mechanism and congestion control are addressed separately.

Each intermediate node along the path, between the source and the destination are treated as TCP proxies. These proxies further divide the path into many segments. Every proxy buffers the packet and forwards it to either next proxy or to the final destination node. Within a segment local acknowledgements are used to acknowledge the packet.

In case of proxy failure, the reliability of the network is ensured by using end to end acknowledgement as an add-on to local acknowledgement. If link goes down in one segment, the Split TCP solves mobility related effects by keeping other path segment operating. The Split TCP does not modify TCP behavior of MANET; instead it uses local feedback rather than end to end feedback.

TCP traffic is Bursty

The performance of mobile ad-hoc network improves substantially using a small TCP congestion window as shown by

Fu et al. in [17]. Based on this concept several approaches have been proposed and listed in the Table 4.

Dynamic congestion window limit

This approach is based on the broadcast characteristics of the wireless medium proposed by Chen et al. In wireless multi-hop networks, the Bandwidth Delay Product (BDP) of the connection depends upon the congestion window limit. Further the author suggests that the value of BDP should not exceed the round trip hop count. In standard IEEE 802.11 the value of BDP is taken as 1/5 of round trip hop count.

In this technique the Dynamic Source Routing (DSR) protocol is used to find the path length at source. The congestion window limit is set dynamically based on previously computed path length of a connection. The author has carried out NS-2 simulation experiments to justify the performance improvement, in comparison with TCP Reno. Further in their simulations the maximum retransmission timeout of TCP is modified to 2s instead of 240s as given in RFC 1122.

Slow Congestion Avoidance (SCA)

In this technique the growth rate of TCP window size is restricted to less than one segment per round trip time, in order to bring down the number of packets in the network. After receiving the successful acknowledgement within round trip time, this technique increases the TCP window size by one segment. The cross layer information of the transport layer protocol is not used to carry on shared channel properties of MANET. The author has not explored the properties of this technique for different traffic load.

Fractional window increment (FeW).

This technique mainly focuses on the manner in which TCP behaves in mobile ad-hoc network by reducing the congestion window growth rate of TCP. The congestion in wireless ad-hoc network usually occurs due to link layer losses rather than queue overflows, thus affecting the routing of packet.

To maintain low loss rate in wireless ad-hoc network, this approach modifies the TCP's operational range. Author claims that, it is evident from the mathematical analysis; the change in the TCP's operational range is accomplished by incrementing the TCP congestion window of wireless ad-hoc network slower than in standard TCP.

Non-work-conserving scheduling

Yang et al.[25] observed MANET connected to a wired backbone , suggested that by reducing the congestion window size it degrades the performance of congestion control for a larger extent.

They proposed Non-work-conserving scheduling mechanism. In this mechanism a timer is set after sending a data packet. In the next step the data packets are not sent by the same Node until the timer expires. This reduces the rate at which the packets are forwarded, at each intermediate Node.

Rate-Based Congestion Control (RBCC)

Zhai et al. in [26] proposed Rate-Based Congestion Control (RBCC) which adopts leaky bucket algorithm. In this mechanism the header is added with a new feedback field which is utilized by each intermediate node along the path. These nodes furnish information about maximum rate of flow at each node.

They study the channel busy ratio, i.e. the time interval at which the medium is non-idle. This information is utilized to modify the newly added feedback field. This helps the source to decide upon the sending rate. Every intermediate node maintains the details of the flow passing through it for later computation of convergence of fairness.

Cross-layer congestion control (C^3TCP)

In this mechanism two network metrics, bandwidth and delay are measured between source and destination by cumulating intermediate hop measurements. This scheme is proposed by Kliazovich et al. Similar to RBCC, a feedback field is added to the link layer header. The collected information at each intermediate node is stored in the feedback field. When ACK is generated at destination node, the feedback information of the data packet is transmitted to the sender. This information is used to modify receiver advertise window field in ACK. Further more it is used to modify the windows size of the sender, which is located beyond TCP stack as an additional module. All C^3TCP logic is part of additional protocol module which performs without disturbing original TCP.

TCP with Adaptive Pacing (TCP-AP)

ElRakabawy et al. proposed a technique TCP-AP. This technique adopts an end to end based approach for congestion control unlike C^3TCP and RBCC. TCP-AP is a mixture of both window and rate based approach. TCP is added with rate based mechanism to avoid large burst of packets.

In this technique the author proposes 4 hops propagation delay as a metric, measured using RTT of the packets. This is assumed as any interference if happens could be within 4 hops. The delay is the time between the transmissions of packet by source node to the receiving node 4 hops downstream.

In order to estimate minimum time between successive packets an addition metric, the coefficient of variation of RTT samples, is used along with the 4 hops propagation delay.

Wireless link losses.

A wireless link is prone for random packet losses unlike wired network. These losses affect the transport protocols performance, if they are wrongly interpreted as congestion induced by dropped packets. The link layer provides single hop reliability in 802.11 MAC protocol. The packets are dropped by link layer, only after maximum transmission attempts. This occurs when either a link is lost or due to packet collision. This section mainly deals with approaches for random packet losses in wireless ad-hoc network. Some of the approaches are listed in Table 5.

TCP with Restricted Congestion Window Enlargement (TCP/RCWE).

Gunes¸ and Vlahovic proposed a technique based on Explicit Link Failure Notification (ELFN) mechanism. In this technique the value of Retransmission Time Out (RTO) is observed randomly.

The congestion window size is increased if the RTO value decreases or remains constant. If the RTO value increases the congestion window size is unaltered. The author has conducted NS-2 simulation using RCWE and found less packet losses and higher throughput due to smaller congestion window. The actual performance improvement due to ELFN is not measured as simulations are based on standard TCP without ELFN.

ADTCP

ADTCP proposed by Fu et al., uses two metrics, *inter-packet delay difference* and *short-term throughput* to detect network congestion. The time elapsed between two successive packets and the throughputs in certain time interval in the immediate past are defined as inter-packet delay difference and short-term throughput respectively. When congestion occurs, *inter-packet delay difference* increases, *short-term throughput* decreases. To detect the channel error and route change, this technique uses out of order packet arrival and packet loss ratio.

In ADTCP the accrued information at the receiver is sent as a feedback to the sender.

Edge-based approach

In this technique, Measured RTT is used by De Oliveira et al. to differentiate between medium losses and congestion. In this approach TCP congestion control reaction is avoided, if medium loss is detected, when packet is not received for longer duration of time. This is identified as route failure. As a remedy this approach enters probe mode, where the packets are transmitted at regular intervals to establish new route. A fuzzy logic based approach is used to distinguish congestion from medium related losses. The author carried out NS-2 simulation to analyze the performance with background traffic.

New Protocols for MANET

In this section we try to present some of the new protocol designs that are tailor-made for MANET environment. These protocols are designed at the cost of standard TCP compatibility and also limited to small and closed environment, where no other transport protocols are used. Some of the approaches are listed in Table 6.

EXACT

EXACT is a protocol designed by Chen et al. using rate based approach. In this technique all the intermediate nodes dedicate itself for monitoring the packet flow through them. These intermediate nodes determine and share the current bandwidth information with their neighbors. When a packet arrives at intermediate node, it checks for the rate information, if the rate is lower than the rate specified, the rate information in the header of the packet is modified before forwarding it. This helps the destination node in updating about the bottleneck rate.

This technique is implemented using two different header fields, one field contains the current rate of the sender and the other is the rate requested by the sending application. This technique also helps in managing the flow rate at router and also informs the sender probable increase/decrease its transmission rate. In case of route failure, a *safety window* prevents the sender from overloading the network. EXACT may be implemented on both reliable (TCP-EXACT) and unreliable (UDP-EXACT) transmission. In EXACT there are no retransmission timers, instead it uses SACK scheme. When a packet is not acknowledged by the receiver or if the received acknowledgement sequence number is too apart from the highest acknowledged packet then it is retransmitted.

Ad-hoc Transport Protocol (ATP)

Sundershan et al. proposed Ad-hoc Transport Protocol (ATP) which adopts rate based approach. This technique does not use retransmission time out and requires limited feedback from the destination. It is also clearly distinguishes between congestion control and reliability mechanisms. In this technique the flow specific information are not used unlike in EXACT. The exponential average of delay of each packet is computed at every intermediate node. This delay includes queuing delay and the time spent at node before it is forwarded. The current delay value is updated only if it is greater than the delay specified in the packets header, thus the destination node is updated with the maximum delay in the path. The accumulated information at the destination node is averaged and sent back to the sender, so that the sender can modify the sending rate.

To estimate the initial sending rate, the sender sends probe packet along the route to gather information of the current sate of the network at each intermediate node. This technique uses SACK for receiving acknowledgments of data packets. A large SACK blocks is used to reduce number feedback packets.

Wireless explicit Congestion control Protocol (WXCP)

Wireless explicit Congestion control Protocol designed by Su and Gross is a variant of XCP transport protocol designed for wired network with high bandwidth delay product. This technique is a window based approach involving rate based element in it. This technique uses multiple congestion metric and explicit feedback within the network. These values are computed at each intermediate node. The three metrics, the local available bandwidth, length of the queue and average number of retransmissions are computed at WXCP enabled intermediate node. The average number of retransmissions is computed to avoid the disturbance caused within the flow. The feedback is a function of relative influence of these three metrics. In this technique separate decisions are taken for congestion fairness control. Fairness controller achieves time fairness among flows rather than throughput fairness. The sender switches to a slow rate based control mechanism due to small congestion window and missing ACKs or duplicate ACKs.

TPA

TPA is a transport protocol for mobile Ad-hoc network developed by Anastasi et al. In this technique the required number of packet retransmission is minimized as compared to standard TCP. A fixed number of packets are grouped into a block and transmitted to the destination. The next block is not transmitted until the acknowledgments for all the packets of the previous block are received. In case of route failure, TPA enters into freeze state, if ELFN mechanism is available, thus decreasing the window size to 1, or otherwise it is detected by number of consecutive timeouts.

The retransmission timeout is set based on RTT like in standard TCP. In case of route change a new set of RTT values are computed. TPA uses window mechanism for congestion control. It use two different cwnd values, a segment size of 2 or 3 during normal operation and a segment size of value 1 when congestion is detected.

Conclusion

In almost all approaches the authors have tried to enhance the capability of MANET. It can be broadly classified into two categories such as, one set of authors tried to achieve improvement in the protocol by matching with TCP, where as others tried to suit MANET at the cost of TCP. It is difficult to analyze the performance gain since there are no comparative study of protocols is available.

This paper mainly deals with survey of congestion control in MANET; is often looked at only issues related to transport layer therefore it is entangled with reliable mechanism (like TCP).

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Approach	Author	Reference
TCP-F	Chandran et al.	[6]
ELFN	Holland and Vaidya	[7]
TCP-BuS	Kim, Toh and Choi	[8]
ENIC	Sun and Man	[9]
TCP-RC	Zhou	[10]
ATCP	Liu	[11]
Preemptive routing	Goff	[12]

Table 1: list of route failure approaches

Approach	Author	Ref
Dynamic delayed ACK	Altman & Jim´enez	[13]
Dynamic adaptive ACK	De Oliveira &Braun	[14]
Preferred ACK Retransmission	Sugano	[15
Combining data and ACK packets	Yuki	[16]

Table 2: list of approaches for TCP Acknowledgement scheme

Approach	Author	Ref
LRED / adaptive pacing	Fu et al.	[17]
NRED	Xu et al.	[18]
COPAS	C de Cordeiro et al.	[19]
CAR	Ye et al.	[20]
Split-TCP	Kopparty et al.	[21]

Table 3: list of approaches for Unfairness between TCP flows induced by shared medium.

Approach	Author	Ref
Dynamic congestion window limit	Chen et al	[22]
Slow Congestion Avoidance	Papanastasiou and Ould-Khaoua	[23]
Fractional window increment	Nahm et al.	[24]
Non-work-conserving scheduling	Yang et al.	[25]
Rate-Based Congestion Control	Zhai et al.	[26]
Cross-layer congestion control	Kliazovich et al.	[27]
TCP with Adaptive Pacing	ElRakabawy et al.	[28]

Table 4: list of approaches for TCP traffic is Bursty

Approach	Author	Ref
TCP with Restricted Congestion Window Enlargement	Gunes¸ and Vlahovic	[29]
ADTCP	Fu et al.	[30]
Edge-based approach	De Oliveira et al.	[31] [32]

Table 5: list of approaches for Wireless links losses.

Approach	Author	Ref
EXACT	Chen et al.	[33][34]
Ad-hoc Transport Protocol (ATP)	Sundaresan et al.	[35]
Wireless eXplicit Congestion control Protocol (WXCP)	Su and Gross	[36]
TPA	Anastasi et al.	[37]

Table 6: list of approaches for New Protocols for MANET