A Survey on Congestion Control on Mobile Ad-Hoc Networks

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***Abstract*— This paper presents a survey of Congestion control approaches in Mobile ad-hoc network (MANET) by taking into account various directions of congestion control research in the said area. It is practicable idea to take a holistic view and study various approaches together for congestion control issues in mobile ad-hoc networks. The main motivation of this work is to summarize the recent approaches in this field of research, identify major issue and challenges in congestion control and motivate further research on this topic.**

Keywords—Congestion Control, Mobile ad-hoc networks, Traffic Acknowledgement Issue

I. INTRODUCTION

Mobile wireless data communication, which is advancing both in terms of technology and usage/penetration, is a driving force, thanks to the Internet and the success of second-generation cellular systems. As we look to the horizon, we can finally glimpse a view of truly ubiquitous computing and communication. In the near future, the role and capabilities of short-range data transaction are expected to grow, serving as a complement to traditional large scale communication. Perhaps the most widespread notion of a mobile ad hoc network is a network formed without any central administration which consists of mobile nodes that use a wireless interface to send packet data. Since the nodes in a network of this kind can serve as routers and hosts, they can forward packets on behalf of other nodes and run user application [1]. In mobile ad-hoc networks, congestion occurs with limited resources. The standard TCP congestion control mechanism is not able to handle the special properties of a shared wireless channel. TCP congestion control works very well on the Internet. But mobile ad-hoc networks exhibit some unique properties that greatly affect the design of appropriate protocols and protocol stacks in general, and of congestion control mechanism in particular. As it turned out, the vastly differing environment in a mobile ad-hoc network is highly problematic for standard TCP [2]. Severe throughput degradation and massive fairness problems are some of the identified congestion related problems.

The number of mobile users as well as the number of applications using mobile devices has increased drastically due to emergence of MANET. The main side effect of this increased load is the problem of congestion in the network. Congestion control is considered as a problem of distributed nature, which requires a solution distributed at source destination ends (transport layer) as well as at intermediate routers (network layer) to handle network congestion. Consequently researchers have considered various aspects of research for congestion control i.e. Route failure, wireless losses, shared medium, acknowledgement traffic etc. This paper presents literature review of congestion control approaches in MANET. Different research questions related to congestion control approaches in MANET are identified. The present work provides insights about the topic by considering the modeling and analysis techniques of congestion control, and some research challenges of the topic. Since this is a comparatively new topic, so we have taken an open search strategy. In this study, standard journals related to computer networks and mobile communication has been selected.

The purpose of this literature survey is to review the Congestion control research for MANET and characterize the different approaches to Congestion control design, by considering their advantages and limitations. Unlike previous studies, an attempt has been made to collect, categorize, and analyze major congestion control approaches in MANET by considering the various aspects of congestion control design. In this way this survey will naturally strengthen the coherency between the various directions of congestion control research in MANET and traces a better picture of major issues, challenges and possible solutions of network congestion problem in MANET.

The paper is organized as follows: In Section 2 of this paper, a brief review of previous surveys, conducted on MANET congestion control, has been mentioned. A short introduction of network congestion and congestion control in general are mentioned in section 3. Research methodology and research questions are explained in Section 4. Section 4 discusses the answers to the major research questions. Finally Section 5 concludes the paper.

II. RELATED WORK

In Literature, the problem of Congestion has been studied widely in the context of high speed network, wireless network, satellite network, ad-hoc network etc. Substantial

survey works have been reported regarding Congestion control in MANET. Some significant survey works related to the topic are as follows.

Lochert, Scheuermann and Mauve have given an overview over existing proposals for congestion control in MANET, explain their key ideas and show their inter-relations. In their survey they have provided an overview of existing attempts to solve the congestion control problem in mobile multi-hop ad-hoc networks. They did not consider approaches aimed at improving congestion control or TCP performance over single-hop wireless networks [3]. Kumaran and Sankaranarayanan have performed a study for congestion free routing in ad-hoc networks based on dynamically estimated mechanism to monitor network congestion [4]. Hanbali, Altman and Nain have written a survey of TCP over Ad hoc networks. They had presented an overview of this comparison and detailed discussion of the major factors involved [5]. Srivastava, Tomar and Bhadauria have presented a survey of congestion adaptive routing protocols for mobile aad-hoc networks. In their survey, they have given an overview of existing approaches that attempt to provide some congestion adaptive routings in mobile ad hoc networks. The existing approaches are systematically described, classified and compared. The approaches that have been selected for analysis are CARM, CRP, CAAODV, AODVM. While their main objective to make routing protocol congestion adaptive is common to all but adaptation and approach is different and have variations in basic characteristics [6]. Sreenivasa, BhanuPrakash and Ramakrishnan have discussed various congestion control approaches in MANET and tried to bring out some of the congestion control techniques and its salient features [7]. Tiwari, Jain, Rana have presented a survey on congestion control mechanisms in mobile ad-hoc networks. They compared various congestion control mechanism used in MANET such as TCP Tahoe, TCP-Reno, New Reno, TCP SACK, TCP FACK, TCP Vegas. Along with the above specified APCC, RED and strategically RED approach to handle congestion is also illustrated. The same is tried to resolve by using concept of explicit congestion Notification (ECN) which is an extension to transmission control protocol (TCP) and allows end to end notification of network congestion without dropping packets which is done conventionally in TCP/IP networks with a bit difference of additional bit and other methodologies available for the same have been discussed [8]. Prajapati and Shah have written a literature survey on congestion control Schemes for Wireless Ad hoc Networks. With help of various simulations thet shown that rate adaptation in MAC layer improves the network performance in terms of throughput, delivery ratio and packet transfer delay; using congestion information from MAC layer in routing discovery improves the performance of the network benefited from overall network load balance [9].

The above contributions demonstrate that although various attempts to survey the congestion control approaches are available in the literature. This paper extends the above contributions further by suggesting a multi-fold approach to study the problem of Congestion in MANET.

III. RESEARCH METHODOLOGY AND RESEARCH QUESTIONS

This study has been undertaken as a systematic literature review based on the original guidelines as proposed by Kitchenham [10]. The identification of research questions is the first step toward the direction of any systematic literature review (SLR). As Research questions have pivot role in literature review, some basic questions related to Congestion control in MANET have been considered.

a. Research questions

The research questions addressed by this study are:

RQ1: Whether Congestion in MANET is assumed a significant challenge?
Motivation: The purpose is to get an idea about the importance of the congestion control problem in high speed computer networks.

RQ2: What are the available methods for Congestion Control in MANET?
Motivation: Obtain an overview of the existing methods in order to be able to refine these methods or propose a new method.

RQ3: What are the available tools for Congestion Control in MANET?
Motivation: Obtain an overview of the existing tools in order to be able to know the strengths and weaknesses of various tools used for congestion control.

b. Search process

Since "Congestion Control in Mobile ad-hoc Network" is relatively new topic, so we choose the open search strategy. Mobile ad-hoc network is a new paradigm and most of the significant works are observed after 2006. Because of this reason, journals and proceeding have been selected since 2006. In random searching, search has been performed at random using keyword related "Congestion Control in Mobile ad-hoc Network", "Congestion Approaches in Mobile ad-hoc Network" , "Routing Algorithms in Mobile ad-hoc Network" etc. We have used Google, Live and Babylon search engine for the purpose. Searching has been done manually. We have gone through those s which are related to Congestion Control in Mobile ad-hoc Network. We have included some survey s also. General computer network s are excluded. s based on traditional wired/wireless networks are also excluded. For understanding purpose some s related to only congestion control are included. The selected study acts as a primary studies for literature review. Inclusion and exclusion criteria are done on the basis of studying abstract and introduction of s from selected journals and proceeding conferences.

c. Search strategy

The search process was a manual search of specific conference proceedings and journal s since 2008. Aforesaid journals and proceedings have been opened manually. Using title of research to select literature relevant to research

questions can mislead to researchers. Exploring complete research of every selected journals and conference proceeding is time taking and cumbersome task because of excessively irrelevant material. In our strategy we have gone through only abstract and introduction part of each . Using abstract and introduction it can be identified that which is relevant to aforementioned research questions. Relevant s would be selected for detailed study. The abstracts containing the keywords 'congestion control', 'routing algorithms' and 'ad-hoc network' would be considered as major research relevant to proposed research questions.

d. Inclusion and exclusion criteria

Peer-reviewed articles on the following topics, published between August 2008 and April 2013, were included:

- *Congestion control for ad-hoc Network* using:
  - Route failure approaches
  - Reverse acknowledgement approaches
  - Shared medium approach
  - Output Limit approach

As congestion control is a wide area of research covering various network domains like traditional network, high speed network, wireless network, wireless sensor network and ad-hoc network etc. Therefore we restricted our search toward the ad-hoc network only.

Articles on the following topics were excluded:

- Rate based Congestion control
- Equation based Congestion control
- Congestion control for traditional Wired Network
- Congestion control for traditional Wireless Network

IV. OBSERVATIONS

In this section, possible answers of aforementioned questions have been discussed.

RQ1: Whether Congestion in MANET is assumed a significant challenge?

In early seventies 'congestion control' comes in picture. 'Congestion control' word was ambiguous in its starting time. Academicians and practitioners had different opinion regarding 'congestion control'. Davies [1] (1972) first considered congestion avoidance an important issue for public data network because these networks provide various facilities which are vital for trade, industry & transport. Rudin [2] (1981) also considered congestion control a significant issue because quality of network performance which user perceives depends upon it. In earlier phase of internet, Nagle [3] (1984) considered 'congestion control' a recognized problem in complex networks. He observed a severe problem of 'congestion collapse' also known as Internet meltdown, which results in a serious downgrade of network throughput. Jacobson [4] (1988) has proposed the earliest solution of congestion collapse termed as TCP based congestion avoidance method. Yang et al [5] (1995) have given a prime concern to congestion control in network research and development due to increasing network bandwidth and diverse network applications and have considered network congestion an actual hazard to the development of internet and communication applications. The Evolution of high speed network raised different issues while designing congestion control mechanisms for large bandwidth delay product network. Congestion control was considered as a serious issue for high speed network and many research issues are identified regarding this [11].

Congestion takes place in MANETs with limited resources. In these networks, shared wireless channel and dynamic topology leads to interference and fading during packet transmission. Packet victims and bandwidth dilapidation are caused due to congestion, and thus, time and energy is wasted during its recovery [12]. Congestion control is the main problem in ad-hoc networks. Congestion control is associated to controlling traffic incoming into a telecommunication network. To avoid congestive crumple or link capabilities of the intermediate nodes and networks and to reduce the rate of sending packets congestion control is used extensively. Furthermore, due to the comparatively low bandwidth of mobile ad-hoc networks, one single sender is able to cause a collapse of the network due to congestion. Thus wireless multi-hop networks are much more prone to overload related problems than traditional networks [3]. In mobile ad hoc networks (MANETs), congestion can occur in any intermediate node, often due to limitation in resources, when data packets are being transmitted from the source to the destination. Congestion will lead to high packet loss, long delay and waste of resource utilization time [13]. In an ad-hoc network, the wireless media is shared by multiple nodes. The contention among neighbours for the access to the shared media is the major cause for network congestion. As wireless links usually have low capacity, congestion in ad-hoc networks is a more severe problem than in wired networks [14]. Congestion is a dominant cause for packet loss in MANETs. Typically, reducing packet loss involves congestion control running on top of a mobility and failure adaptive routing protocol at the network layer [15].

It can be observed from the above that Congestion in MANET is assumed a challenging problem by the academician/practitioners?

RQ2: What are the available methods for Congestion Control in MANET?

An effective congestion control solution is supposed to be an important concern for MANETs. Various network congestion issues are mentioned in literature. Many congestion control solutions are also mentioned in literature that well addressed the network congestion issues in context of ad-hoc networks.

Approach	*Source of* Congestion Information	Strengths/Weakness	Parameters	Experimental Method	Reference
A feedback scheme, whereby the source can distinguish between route failure and network congestion	*Route Failure Notication(RFN), Route Re-establishment Notification(RRN)*	*This approach leads to unnecessary retransmissions and loss of throughput.*	*failure rate, route re-establishment delay (RRD)*	*Simulation using NS2*	*[16]*
Investigate the effects that link breakage due to mobility has on TCP performance	*TCP throughput, explicit link failure notification (ELFN)*	*This approach provides a more accurate means of performance comparison by accounting for the differences in throughput when the number of hops varies.*	*expected throughput*	*simulations using the ns network simulator*	*[17]*
TCP-BUS	*ERDN(Explicit Route Disconnection Notification), ERSN(Explicit Route Successful Notification)*	*Avoiding Unnecessary Requests for Fast Retransmission*	*Extending Timeout Values*	*simulations using the ns network simulator*	*[18]*
TCP-RC	re-compute cwnd and ssthresh for the TCP connection after route is reconstructed	TCP-RC had achieved better TCP performance than Reno in ad hoc network.	cwnd and ssthresh	*simulations using the ns network simulator*	*[19]*
TCP-DOOR	out-of-order delivery events	improve TCP performance by detecting and responding to out-of-order packet delivery events	Out-of-Order ACK Packets, Out-of-Order Data Packets	*simulations using the ns network simulator*	*[20]*

Table 1: Summarization of Route Failure Issues in MANET

These solutions are originating from data link layer, network layer and transport layer. In this section an attempt has been made to summarize the existing congestion control approaches in literature covering ad-hoc networks. There is no perfect solution for congestion control that addresses all the concerned issues of mobile ad-hoc networks and said as complete. The available solutions rather address a subset of the identified issues. In order to limit the discussion, we have considered congestion control approaches for multi-hop networks and ignore approaches for single hop networks.

In order to make the answer structured, we group the available solutions based on the main issues that they focus on. The major issues that we identified for discussion are: route failure, wireless losses, shared medium and data and acknowledge traffic. In the following subsections, the above mentioned issues are discussed subsequently.

(a) Route Failure Issue

If a route failure occurs in mobile ad-hoc networks, then the time required for searching an alternate route puts a negative effect on congestion control mechanism. During this route failure period neither the data packets can be sent nor can acknowledgement packets be received. It will force the sender to sender to reduce the window size. The approaches dealing this issue are summarized in table I.

The topology of an ad-hoc network changes due to the movement of mobile hosts, which may lead to sudden packet losses and delays. Transport protocols like TCP, which have been built mainly for fixed networks, misinterpret this loss as congestion and invoke congestion control. Chandran et. al. have proposed a feedback based scheme, in which the failure point notifies the source of route failure and route re-establishment, thus distinguishing route failures from congestion [16]. Holland and Vaidya investigated the effects of mobility on TCP performance in mobile ad hoc networks. Through simulation, they noted that TCP throughput drops significantly when node movement causes link failures, due to TCP's inability to recognize the difference between link failure and congestion. They also introduced a new metric, expected throughput, which provides a more accurate means of performance comparison by accounting for the differences in throughput when the number of hops varies. Kim, Toh, and Choi have examined issues related to TCP communications over ad hoc wireless networks. In particular, we reveal the confusion faced by a TCP sender - that of delay and packet loss due to route reconstruction as a result of host mobility and that of network congestion. They improve TCP performance by proposing intelligent buffering and sequence checking techniques. They also introduced the ERDNGENSEQ and ERDNRCVSEQ mechanism, which adjusts timeout values to compensate for route reconstruction time, and avoids unnecessary requests for fast retransmission and selective retransmission of lost packets [18]. Zhou, Shi and Zou proposed a new approach, TCP-RC, which re-compute cwnd and ssthresh for the TCP connection after route is reconstructed, thus it can adjust the TCP transmission rate adaptively according to current capacity of TCP connection. Consequently, TCP-RC lowers possibility of bursty traffic and avoids invoking congestion control under situation of high
network load. Analyses and simulations show that TCP-RC had achieved better TCP performance than Reno in ad hoc network. Wang and Zhang explored a new way to make TCP

adapt to frequent route changes without relying on feedback from the network. It is based on TCP detecting out-of-order

Approach	*Source of* Congestion Information	Strengths/Weakness	Parameters	Experimental Method	Reference
investigate the use of fuzzy logic theory for assisting the TCP error detection	*congestion from packet loss by wireless induced errors*	*enhancing the TCP error detection mechanism*	*Round Trip Time (RTT), retransmission timeout (RTO)*	*Network simulator NS2*	*[21]*
Involve only the end nodes in the congestion control performed by TCP	*RTT variation monitoring as congestion indication*	*No specific cooperation from intermediate nodes is needed*	*round trip time (RTT),*	*Network simulator NS2*	*[22]*
Perform multi-metric joint identification for packet and connection behaviors	*End-to-end measurements are used to detect congestion, disconnection, route change,*	*Multi metric based approach*	*IDD (Inter Delay Difference) and STT (Short Term Throughput)*	*Test-bed measurements and ns-2 simulations*	*[23]*
The restricted congestion window enlargement (TCP/RCWE)	*Congestion window*	*TCP/RCWE improves TCP by adapting its behavior to the ad-hoc network environment.*	*smoothed round trip time(SRTT), retransmission time out(RTO)*	*Network simulator NS2*	*[24]*

TABLE 2: Summarization of Wireless Loss Issue in MANET

delivery events and inferring route changes from these events. We call it Detection of Out-of-Order and Response (DOOR). Their study has shown that this approach can significantly improve TCP performance over mobile ad-hoc networks [20].

(b) Wireless losses

In wireless environment, the probability of random packet loss is more than the wired networks. These losses are related to the performance of transport layer if we misinterpreted packet drop as congestion in network. In mobile ad-hoc network, this problem is very significant. Research efforts related to this issue are summarized in table II.

Oliveira and Braun have introduced and evaluated a fuzzy logic engine for supporting TCP error detection mechanism in ad hoc networks. The architecture of the enhanced error detector has been explained, and its primary features discussed. The main conclusion of their work is that efficiency can be obtained provided that the input data are taken precisely enough to reflect the actual changes inside the network. This implies that a minimum number of ACKs is needed to ensure efficiency in the results. This is an end-to-end scheme which requires only end nodes cooperation [21]. Oliveira, Braun and Heissenbüttel have described the general principles of end-to-end approach for improving TCP in ad hoc networks. Additionally, they have presented early simulation results carried out to evaluate whether RTT monitoring can be a good indicator of network congestion. They propose to evaluate the reliability of using RTT variation monitoring as congestion indication. The main advantages of their approach are simplicity and independence of intermediate nodes cooperation [22]. Fu, Greenstein, Meng and Lu implement their design only at the two end hosts, and do not rely on any explicit network notification mechanism. End-to-end measurements are used to detect congestion, disconnection, route change, and channel error, and each detection result triggers corresponding control actions. They first describe the necessary network states in an ad hoc network to be identified by TCP, and then examine metrics that can be measured end-to-end. In particular, two metrics are devised to detect congestion, IDD (Inter Delay Difference) and STT (Short Term Throughput). They each exhibit a unique pattern upon congestion; and in non-congestion states, they are influenced by different network conditions in such a way that their respective measurement noise is largely independent. [23]. Gunes and Vlahovic have presented an enhancement to improve TCP's performance in mobile multi-hop wireless ad-hoc networks, called TCP/RCWE. Their enhancement is based on enabling TCP to distinguish between causes of packet loss, e.g. high bit error rate and congestion, and adapt TCP to the current network state. In contrast to other studies on TCP, they did not only consider the effects of node mobility and packet size on TCP's performance, but also the effects of medium disturbances, resulting in high bit error rates [24].

(c) Shared Medium Issue

In a mobile ad-hoc network the medium is shared by all nodes. This may be useful to analyze congestion problem in certain area in spite of certain specific node. This issue has significant impact on congestion control solution. It defines congestion as spatial phenomenon that occurs in a certain area not to specific node. The research efforts covering this issue are summarized in table III.

Approach	*Source of* Congestion Information	Strengths/Weakness	Parameters	Experimental Method	Reference
Study the effect of multi-hop wireless link on TCP throughput and loss behavior	TCP Throughput	There exists a TCP window size, say W*, at which its throughput is highest through improved spatial channel reuse.	TCP Throughput	*Network simulator NS2*	*[25]*
Neighborhood Random Early Detection (NRED) scheme	channel utilization, neighborhood queue size	NRED scheme is basically a distributed RED suitable for ad hoc wireless networks	Queue Size	*Network simulator NS2*	*[26]*
To enhance TCP performance by avoiding Capture conditions.	*Average End-to-End Delay*	*COPAS can be deployed on top of any on demand routing protocol, such as DSR and AODV.*	*Throughput, Average number of back-offs per second*	*Network simulator NS2*	*[27]*
Study of spatially separating TCP connections by implementing routing functionalities	*TCP performance with Centralized Congestion-Aware Routing (CCAR)*	*Thorough investigation of spatial separation of TCP connections*	*weight of the node (W_{node}),weight of the Link(W_{LINK})*	*Network Simulator ns-2*	*[28]*
An enhancement of TCP-Friendly Rate Control (TFRC) named as RE TFRC	roundtrip time and wireless delay	reduction in round-trip times, reduction in the loss event rate	Rate Estimation (RE), saturation capacity of the MAC layer	*Network Simulator ns-2*	*[29]*

Table 3: Summarization of Shared Medium Issues in MANET

Fu et al have demonstrated (with analysis and simulations) that, given a specific network topology and flow patterns, there exists a TCP window size W∗, at which TCP achieves best throughput via improved spatial channel reuse. However, TCP does not operate around W∗, and typically grows its average window size much larger; this leads to decreased throughput and increased packet loss. The TCP throughput reduction can be explained by its loss behavior. Their results show that network overload is mainly signified by wireless link contention in multi-hop wireless networks. As long as the buffer size at each node is reasonably large (say, larger than 10 packets), buffer overflow-induced packet loss is rare and packet drops due to link-layer contention dominate [25]. Xu et. al. have proposed a scheme called Neighbourhood RED, which is an extension of the RED originally developed in the wired network to ad hoc wireless networks. By detecting early congestion and dropping packets, the NRED scheme is able to improve TCP fairness. The major contributions of their work are the concept of a distributed neighbourhood queue (without which the RED scheme does not work) and the design of a network layer solution that does not require MAC modification [26]. Cordeiro, Das, and Agrawal have proposed a novel algorithm, called COPAS, that achieves this using two techniques ─choosing disjoint forward and reverse paths for TCP data and ACK packets and contention-balancing the whole network. Contention-balancing takes into consideration the number of MAC layer back-offs the nodes have experienced recently. COPAS can be deployed on top of any on demand routing protocol, such as DSR and AODV. Through extensive simulations, they have demonstrated that COPAS provides up to 90% improvement in TCP throughput than baseline DSR [27]. Ye, Krishnamurty and Tripathi have demonstrated that the overhead that is necessary for achieving distributed congestion-aware routing in wireless ad hoc networks severely undermines the spatial diversity gains achieved. They perform a thorough investigation of whether spatial separation of TCP connections can provide benefits and explore a distributed way of achieving the gains. First, they investigate if they can obtain performance gains through separating TCP connections spatially in ad hoc networks, with a centralized ideal approach. Their studies suggest that the benefits due to spatial separation of TCP connections do exist. However, the benefits only apply to long TCP connections [28]. Li et al have presented a new algorithm, Rate Estimation (RE) TFRC, designed to enhance TFRC performance in wireless Ad Hoc network environment. RE TFRC estimates a sending rate using an optimal round-trip time based on the network topology and equivalent loss event rate. The optimal round-trip time is estimated by modeling multi-hop contention delay and service time and the equivalent loss event rate is estimated using the inverse TCP Friendly rate equation with the optimal round-trip time. The basic idea is to infer the lower-layer MAC layer jamming in the upper layer TFRC to make it aware of lower layer congestion and reduce the jamming effects [29].

(d) Acknowledgement Traffic Issue

The question arises how the amount of ACK traffic or at least its negative impact on the performance of the forward channel can be minimized. This is closely related to the effects caused by the shared medium in general. Consequently there is some overlap with the previous section, and some of the approaches described there also consider the interplay between oppositely-directed data and ACK traffic [ref3]. The research efforts covering this issue are summarized in table IV.

Approach	*Source of* Congestion Information	Strengths/Weakness	Parameters	Experimental Method	Reference
delayed ACK scheme	*queue length*	*obtain a performance of TCP which is good for a large range of number of nodes*	*queue length, Delayed Ack Time Interval*	*Network Simulator NS2*	*[30]*
suppressing degradation of the TCP performance by short-time link failure	*Explicit Link Failure Notification (ELFN), Explicit Route Disconnection Notification (ERDN) message*	*uses a table-driven type of routing protocol paying attention to short-duration link failure*	*TCP throughput*	*Network Simulator NS2*	*[31]*
improve TCP performance by combining data and ACK packets	*Data packets queue and ACK packets queue*	*applicable to generic ad hoc networks easily*	*TCP throughput*	*Network Simulator NS2*	*[32]*

Table 3: Summarization of Acknowledgement Traffic Issue in MANET

Approach	*Source of* Congestion Information	Strengths/Weakness	Parameters	Experimental Method	Reference
an energy efficient and cooperative congestion control protocol	*Queue Size*	adjust the multicast traffic rate at each bottleneck of a multicast tree.	*Residual Energy*	*Network Simulator NS2*	*[33]*
Energy efficient multicast congestion control	*Queue Size*	*scheme has very limited control traffic overhead and delay*	*queue size*	*Network Simulator NS2*	*[34]*
TCP-New Veno	*congestion window*	*energy efficiency of mobile device and utilization of bandwidth are improved by the scheme*	*T throughput, , slow-start threshold*	*Network Simulator NS2*	*[35]*
congestion-aware routing metric for MANETs.	*data rate, queuing delay, link quality, residual energy and MAC overhead*	*attains high throughput and packet delivery ratio, by reducing the energy consumption,*	*Data-rate , Buffer queuing delay, Residual Energy*	*Network Simulator NS2*	*[36]*

Table 4: Summarization of Energy Issue in MANET

Altman and Jimenez have shown in their that Delaying Ack (as defined in RFC 1122) improves the performance of TCP over static multi-hop networks that uses IEEE802.11 as MAC. Increasing the number packets that are acknowledged by an ACK to d>2 (which is not recommended in RFC 1122) further improves the throughput. The improvements are due to the fact that ACKs and TCP packets contend over the same channel, so decreasing the throughput of ACK can improve the throughput of TCP. They showed that its performances in terms of delay, loss probabilities and throughput outperform those of delayed ACK schemes with fixed d for large values of maximum window. [30]. Sugano and Murata have described a new technique for improving TCP performance in an ad hoc network that uses a table-driven type of routing protocol paying attention to short-duration link failure. They took as the object of research a Flexible Radio Network (FRN) which is an ad hoc network for data collection. They also evaluated the case in which the effect of the collision of a data packet and an ACK packet is suppressed by Delayed ACK and resending the ACK packet preferentially. They showed through simulation the combination of these improvements can increase TCP throughput about 20% [31]. Yuki et al have analyzed the problem of packet collision in an ad hoc network resulting from the bidirectional communication of TCP. They have proposed a technique that combines data and ACK packets, and have shown through simulation that this technique can make radio channel utilization more efficient. In the simulation, the technique improved the TCP performance by up to 60%, and by about 10% even when the network load was very high. It can be expected that the method which they proposed is effective not only in a specific ad hoc network but the general ad hoc network which the collision of bidirectional communication generates [32].

(e) Energy Issues

Many ad-hoc wireless network nodes will be powered by batteries with limited lifetime. Some of the most exciting applications for ad-hoc wireless networks are in energy constrained category. Energy constraints impact both the hardware operation and the signal transmission associated with node operation. Design with rechargeable batteries must conserve energy to maximize time between recharging. The research efforts covering this issue are summarized in table V.

Chowdhury, Mir and Kowsar have presented an energy efficient and cooperative congestion control protocol to control the congestion in mobile ad-hoc networks (MANETs). The proposed scheme overcomes the disadvantages of existing multicast congestion control protocols which depend on individual receivers to detect congestion and adjust their receiving rates. In the first phase of the proposed protocol, it builds a cooperative multicast tree rooted at the source, by including the nodes with higher residual energy towards the receivers. In the second phase of the proposed protocol, it proposes an admission control scheme in which a cooperative multicast flow is admitted or rejected depending upon on the output queue size. In the third phase of the proposed protocol, it proposes a scheme which tests whether the relay node has the potential path to the required destination, if not then choose the another node which has the second highest residual energy as a new relay node. That is more generally introduction of cooperativeness and making it. In the fourth phase, they propose a scheme which adjusts the multicast traffic rate at each bottleneck of a multicast tree [33]. Rao et al have proposed to design an energy efficient and reliable congestion control (EERCCP) protocol for multicasting with the following phases. In its first phase, it builds a multicast tree routed at the source, by including the nodes with higher residual energy towards the receivers. Most of the existing schemes(AODV) depend on individual receivers to detect congestion and adjust their receiving rates which are much disadvantageous. In the second phase, they propose an admission control scheme in which a multicast flow is admitted or rejected depending upon on the output queue size. In the third phase, they propose a scheme which adjusts the multicast traffic rate at each bottleneck of a multicast tree [34]. Cho and Chung have propose TCP-New Veno in order to improve the energy efficiency of mobile device. According to the network state, the scheme adjusts appropriate size of congestion window. Therefore, the energy efficiency of mobile device and utilization of bandwidth are improved by the scheme. From the simulation by using ns-2, they have shown more improved energy efficiency with TCP-New Veno than those with TCP in MANETs [35]. Baboo and Narasimhan have developed an energy efficient congestion aware routing protocol which employs a combined weight value as a routing metric, based on the data rate, queuing delay, link quality, residual energy and MAC overhead. They have used a multipath on demand routing protocol which discovers multiple disjoint routes from a source to destination, as our basis. Among the discovered routes, the route with minimum cost index is selected, which is based on the node weight of all the in-network nodes from the source node to the destination node [36].

RQ3: What are the available tools for Congestion Control in MANET?

Mobile ad-hoc networks have high cost and lack of flexibility, so, experimentation is mostly achievable through simulation. This section provides a State of the Art of MANETs simulators and associated simulation techniques. The purpose is to know the strengths and weaknesses of various tools used for congestion control. The idea is to get to know that weather existing tools are sufficient for the purpose or it is require revising the tools or proposing a new one in context of newer requirements of mobile ad-hoc networks. Design, development and evaluation of network protocols are a complex task involving various phases. Among them the experiment and evaluation phases, which eventually provides a global view, are vital steps in research and development process of distributed applications and communication protocols. In this context, three standard methods of research and development commonly used are ***simulation***, ***emulation*** and ***live experimentation*** [42].

Here we summarized some MANET's simulators currently in use. For this discussion, we did not consider the wired network simulators and sensor network simulators.

NS-2

NS began as a variant of the REAL network simulator in 1989 and has evolved substantially over the past few years. NS provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless (local and satellite) networks. Its behavior is highly trusted within the networking community. It is developed at ISI, California, and is supported by the DARPA and NSF [3]. NS-2 provides a set a randomized mobility models, including random waypoint. Advanced node mobility had been making available by the Graph Mobility project, the GEMM project, and the Obstacle Mobility model. These constitute a progress towards realistic simulation.

ANSim

ANSim is a network simulator developed for Mobile ad-hoc networks [44]. ANSim is a tool written in Java with a nice intuitive GUI (It even runs as an Applet). The user provides input parameters that specify the simulation like size and shape of the field and the number of nodes for the simulation. The user will receives as result for example the probability that two randomly selected stations are connected. With ANSim, based on a simple transmission model one can calculate connection probabilities of ad-hoc

networks. Simulations based on ANSim provide precise results even for a large number of nodes. All results of static investigation are still valid if mobility does not change the node distribution. The limitations of the Analytic approach occur when dealing with large number of nodes.

GloMoSim

GloMoSim is a library-based sequential and parallel simulator for wireless networks. It is designed as a set of library modules, each of which simulates a specific wireless communication protocol in the protocol stack. GloMoSim has been designed to be extensible and composable: the communication protocol stack for wireless networks is divided into a set of layers, each with its own API. Models of protocols at one layer interact with those at a lower (or higher) layer only via these APIs. The modular implementation enables consistent comparison of multiple protocols at a given layer. The parallel implementation of GloMoSim can be executed using a variety of conservative synchronization protocols, which include the null message and conditional event algorithms [37].

Jane Simulator

JANE (Java Ad hoc Network Environment) is intended to support ad hoc network researchers in application and protocol design. The JANE environment described in this work provides ad-hoc network developers a middleware which can be used to implement and test protocols and applications by following the described three-tier design paradigm. Component based design and asynchronous communication among components are forming the key ingredients of the JANE middleware. The approach is motivated by the observation that realizing a “traditional” view of the network stack and stream oriented synchronous communication does not cope well with the extreme dynamics of an ad hoc environment. For instance, a process blocked at a stream in order to obtain data from another mobile device might frequently be tied up with error handling due to stream disconnection [38].

Madhoc

Madhoc is a metropolitan ad-hoc network simulator targeting the investigation of ad hoc grid-computing . It features the components required for both realistic and large-scale simulations, as well as the tools essential to an effective monitoring of the simulated applications. Madhoc targets the simulation of metropolitan networks. So far, only few research projects have focused on this. The initialization of mobility and Altering the resolution of the simulation are difficult in this simulator. Madhoc targeted to the simulation of numerous mobile stations evolving in metropolitan environments. Madhoc already permitted the development of a couple of bandwidth-efficient broadcasting protocols [39].

J-Sim

JavaSim is an object-oriented simulation package written in Java and available free to users since 1997.The system also comes with complete examples and test routines which illustrate many of the issues raised in using the simulation package. The core of the system gives SIMULA-like simulation routines, random number generators, queuing algorithms, and thread package interfaces.This tool has various statistical gathering routines, such as histogram and variance classes. In this tool classes allow "non-causal" events, such as interrupts, to be handled [40].

NAB

NAB is a simulator developed by the authors of EASE. It is designed to simulate wireless ad hoc and sensor networks. A distinguishing feature of NAB is that it is written in OCaml.NAB is a network simulator targeted at wireless ad hoc and sensor networks. It is developed within the MICS project at EPFL.NAB places a particular emphasises on scalability and visualization. Routing protocols currently implemented are AODV, EASE, and FRESH. Various MAC layers are available including a null MAC and a CSMA MAC [41].

Because of the complex nature of the MANETs, their simulation is a very challenging issue. Simulators rely on various techniques for improving their accuracy, speed, scalability, usability, etc. MANETs simulators exhibit different features and models. The choice of a simulator should be driven by the requirements [tool2].

5. CONCLUSION

This work explores the literature review of congestion control algorithms in the context of mobile ad-hoc networks. We understand that the identified issues and challenges regarding the congestion control algorithms may help in future research in this area. This initial proposition of such a review may be purposefully used by the academician/researchers and the corresponding useful feedback may be analyzed. It calls for further extensive research oriented studies, by all concerned, for identification of newer issues and challenges in this topic.

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