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Improving the Performance of MANETs using the Feedback Based Adaptive Speedy TCP applied with Adept Route Yielding Algorithm

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Abstract

The fast-paced digitization of the world including the explosive growth of IoT, has resulted in an imminent need towards improving the efficiency of Ad-Hoc Networks driving them. In the Ad-Hoc world, the performance of TCP is impaired due to various factors like route failures, node failures, delay, node-mobility, power, etc. and thus the principle challenge in MANET is to choose a dependable, optimal solution to overcome these TCP limitations. The authors have proposed the new algorithm to overcome inherent limitations in TCP using their novel multi-pronged strategy which is described in details in the subsequent research design section. The first part consists of technique to overcome node failures, route failures, packet losses and improve overall throughput while the second one, named as “Adept Route Yielding Algorithm” works towards determining the optimal route to which the current node can forward the packets to. The two approaches, though capable of deployment and functioning independent of each other, have been identified to give better overall results and collectively named as “Feedback-based Adaptive Speedy Transmission Control Protocol”.

Keywords: Adept Route Yielding Algorithm, Feedback-based Adaptive TCP, Ad-Hoc Networks for IoT, Mobile Ad-Hoc Networks, TCP Performance in ANETs, TCP-DOOR.

INTRODUCTION

This paper is an amplified research of our past work titled "Feedback-based Adaptive Speedy Transmission (FAST) Control Protocol to Improve the Performance of TCP Over Ad-Hoc Networks” that was presented in ICACCI-2016 conference held in Jaipur, India [1] wherein the authors presented a novel methodology to overcome the key network performance impairments of TCP over Mobile Ad-Hoc Networks.

MANET introduces to a clear assortment of remote system that includes the group of mobile nodes that can communicate with one other with no help getting from secure/fixed frameworks [2][3]. Transmission Control Protocol is intended for Ad-Hoc and other wired systems. In any case, because of the rising advancements like IOT, Cloud-based administrations, VANET and so on that are fundamentally remote Ad-Hoc availability driven, the necessity to receive Transmission Control Protocol in Ad-Hoc Networks has picked up essentialness. This is the foundation of the wireless revolution like growing of network being cellular networks, personal area networks, radio networks, local area networks. The crucial aim is to create and develop connectivity and the performance which is not compromised for the mobile devices. However, this props up few challenges as the Transmission Control Protocol has poor execution in MANET on account of dynamic topology, shared medium, multi-hop engineering, highly error prone proportion, limited power and channel implication[4].

TCP was developed to give reliable EOE data delivery over unreliable networks (Murthy, 2012). According to Hanbali et al (2005), TCP (Transmission control protocol) is the consistent protocol in the transport layer of fixed networks and applied for internet applications. TCP is considered for fixed link because of its efficiency. Moreover, TCP has native mechanism designed for controlling the congestion and was developed to robustly respond to the dynamic changes in the network[5][6].

Hence, for Ad-Hoc systems to work effectively, suitable covenant level controls ought to be fused to acquire inefficient facets that govern the execution of TCP in Ad-Hoc Networks. It is also significant to embrace effective routing strategies to enhance the quality of communication. Unlike fixed networks, the inherent characteristics of MANETs tend to deteriorate the TCP performance. Factors such as contention, non-fixed nature of channels, along with fading and interference, hidden terminals causing vulnerability of shared-media, random-access-collision, exposed terminals as well as high mobility resulting in frequent breakages of routes pose a high threat to TCP in case of its ability for giving accurate end-to-end communications in MANETs [7][8]. The key success criteria for a protocol to be adopted in MANET include factors like flexibility to adapt and adopt to the changes in topology, have distributed architecture, less maintenance and computational overheads and efficiency of resource utilization[6]. Therefore, this research intends to focus on developing a solution towards improving the efficiency of TCP when deployed in MANETs.

LITERATURE SURVEY

Anantharaman et al. studied the TCP Performance in MANETs and showcased the key factors impacting the performance of TCP over Ad-Hoc Networks using simulated outcomes [9]. They captured various statistics like detection of link failures, calculating link latency, packet-level and flow-level unavailability index of routes for establishing the mobility of routes. The impact of mobility of on the TCP performance was established via loss-rate, throughput and the values of retransmission timeouts at the transport layer. The outcome of their study implied that earlier approaches towards enhancing the TCP performance in MANET acted upon only a limited set of factors. In addition to this, the researches also developed a framework called Atra comprising of three simple and easy ways to enhance the TCP performance at the Transport and MAC layers. This ATRA framework was observed to improve the default TCP stack performance between 50% to 100%.

Holland and Vaidya analyzed the effects of mobility on the performance of TCP in MANETs [10]. They established via simulations the impact on the throughput of TCP owing to the failures in the link caused by the mobility of nodes. This established the fact that TCP failed to distinguish the difference between failure of links and packet losses due to congestion. They also proposed a unique metric called “Expected Throughput” that was considered to be a more accurate way of measuring performance by considering the variations in throughput due to changes in the number of hops. This metric showcased that the Explicit Link Failure Notification could be useful in enhancing the performance of TCP and gave the statistics to substantiate it by comparing the notifications for various protocols. Thus it was proved from the analysis that the metric of Expected Throughput that gave a more definite way of computing performance is compared by accounting for the variation in throughput when number of hops varied.

Karlsson et al. discussed some aspects of TCP performance in Hybrid MANETs by employing various simulations [11]. In this research, they discussed about the multi-hop paths adopted by the un-fixed nodes for connecting to the Internet. This vision permitted expansion of the hotspot coverage which is significant for the 4th generation networks. Since TCP/IP has become the de-facto standard in Internet, this is extremely critical in providing a reliable performance

Katuka et al. stated that TCP performed well at the transport layer in conventional wired networks having low BR (Bit Error) rates [12]. Further, the fundamental assumptions in the design of TCP protocol are violated in the networks with higher BR rates like with mobile hosts and wireless links, resulting in the degradation of end-to-end performance. In this research, they explored various approaches to tackle these issues while concluding that one or more ways to improvise the protocol behavior were essential depending on the link types.

Shukla et al. researched on cross-layer techniques for improving TCP performance in MANETs [13]. The baseline assumption of TCP that the packet losses is primarily owing to the underlying network are not valid on Ad-Hoc, Unfixed networks. TCP performs well if there is no external interference in the communication. In this particular research, it was highlighted specifically that the factors like mobility of nodes, wireless-channels and outcome of handoffs in case of single and multi-hop networks, frequent route changes, MAC layer contentions and breakages are taken to deteriorate the performance of TCP in Ad-Hoc Networks. Thus it could be concluded that TCP works well only if there is no interruptions or interferences.

Patel et al. stated the need for bigger TCP window size sighting the congestion control algorithm as a very important constituent [14]. In contrast, a bigger size of the window would cause the exhaustion of radio resources. Hence the authors attempted to improve upon the congestion control mechanism. They proposed means of enhancing the working of TCP Westwood by making use of the fact that it excluded the buffer size of the routers. For every packet that is transmitted by a source node, a timer indicating the acknowledgement window is set during which the destination node has to acknowledge the receipt of the packet.

Bhanumathi et al. stated that Bandwidth Delay Product can definitely be a critical parameter in identifying best variation of TCP for a given application [15]. Maadani et al. commented that Delay caused by non-deterministic behavior of Ad-Hoc Networks and Wireless in general is a significant parameter when measuring the performance statistics [16]. Shariatmadari et al. and Tan et al. commented on significance of Packet Delivery Ratio and Signal to Noise Ratio as quantifiable metrics in measurement of TCP performance in MANETs [17, 18]. Similarly, Gururaj et al. commented on use of HSTCP in improving the performance of TCP over MANETs by working on the congestion control mechanism in TCP [19].

Thus many researchers have conducted various studies in the past to identify the factors impacting the performance of TCP in MANETs as well as on the parameters that can be used for statistically proving them but hardly any solution has been recommended that can holistically address multiple factors responsible for the performance degradation. This study is aimed to bridge this gap by evaluating these contemporary approaches and identifying a comprehensive technique for effectively assimilating a stable and enhanced performance of TCP over MANETs by combining some of these techniques and improvising on them

RESEARCH DESIGN

The main aim of the study is to design a solution for improving the performance of TCP to be used over MANETs. This is executed over the following two phased approach.

Phase-1: Overcoming limitations of TCP in determining packet losses owing to factors other than congestion

As discussed earlier, since various researchers have proposed different solutions to address this problem, this study has shortlisted the following key modifications made to the TCP protocol including (a) Detection of Out of Order Delivery (b) End to End Approach (c) Feedback Scheme (d) Adaptive Back-Off Response Approach and (e) HSTCP. Based on the conclusions of past researchers, the parameters of Throughput, End-to-End Delay, Packet Delivery Ratio and Signal to Noise Ratio were identified to benchmark the performance [20, 21]. Secondary research methodology also helped to establish that the combination of Feedback + Adaptive approaches could prove to be the most effective way of efficiently handling the way TCP would react to the packet losses owing to parameters other than congestion and node / link failures caused owing to mobility of nodes.

Table 1: Comparison of the four key protocols for enhancing TCP performance in MANETs [1]

Protocol	**Summary of Findings**
Detection of Out of Order Delivery	Performs well in terms of interaction between TCP and media access control (MAC) and TCP congestion size of window [22]
End to End approach	Performs well in terms of interaction between TCP and MAC, energy constraint. [23]
Feedback Based Scheme	In the failures of route event, as the re-establishment of route time maximizes and then the adoption of feedback approach gives main increase in savings in unnecessary transmissions of packet (packet delivery ratio) and throughput[24]
Adaptive Back-off Response Approach	Adaptive TCP performs well than others variants and produces more than 100 percent in the performance of throughput and more than 60 percent of enhancement for utilization of bandwidth than existing methods [25]

The next change underlying behavior of TCP to HS-TCP/MX-TCP (whichever among these two is possible). This research explains about the suitable ways of both HS-TCP and its variation MX-TCP as they have been found to significantly impact the TCP behavior without interfering with any routing protocols [15, 26]. This study is implemented in the network simulator 2 (NS2) tool and the findings were revalidated using OMNET++ to make it agnostic to the simulation tool. The detailed process is described in the Phase-2 below.

Phase-2: Identifying the most optimal path from Source to Destination adaptive to changing network dynamics (called “Adept Route Yielding Algorithm”)

Additionally, many MANET Routing Protocols like Distance Vector (AODV) (RFC 3561) Dynamic Source Routing (RFC 4728), Optimized Link State Routing Protocol (OLSR) (RFC 3626, RFC 7181), etc. have been developed earlier. These protocols though have been lagging in providing most optimal route in terms of throughput from Source to Destination. These protocols have been unable to substantially supplement the improvement in performance of TCP as they could effectively handle only few of the metrics in determining the end-to-end route in a static manner, thus effectively limiting their capabilities to react to the changing dynamics of MANETs. The Phase-2 of the recommended solution titled “Adept Route Yielding Algorithm” effectively tries to derive a weightage or a optimal cost metric from parameters like Bandwidth (or line rate), Delay (or Latency), Hop Counts, Node Mobility and Link Lifetime to propose the most efficient path from Source to Destination and vice-versa. This also accounts for the scenario of asymmetric paths wherein there could be difference in uplink / downlink bandwidth and latency.

The proposed protocol, code named “Feedback-based Adaptive Speedy TCP” comprising of Phase-1 and Phase-2 is expected to address not only the intermediary transmission issues in Ad-Hoc Networks, it is also expected to significantly manipulate the way the Sender and Receiver see the network (or rather get the perception of Network) by making them believe that the Ad-Hoc Network is no less good than a fixed network and allowing them to fully utilize it to their maximum potential.

DISCUSSIONS AND FINDINGS

1. Phase-1: Solution for Optimizing the actual data transfer by mitigating packet loss, packet drops, node failure and link failure scenarios and enhancing the throughput.

The proposed solution addresses these issues in a two pronged strategy – One is to overcome the effect of packet losses and Second is to enhance the end-to-end throughput by suitably manipulating the congestion window.

Stage-1 of Phase-1 : The working principle of the first stage is described as follows:

When a sender node initiates the request for transfer of data to the receiver node, the initiator starts determining the route to reach out to the destination.

Once the routing table is determined, then next step will be to overcome the plausible factors responsible for degrading the end to end performance of TCP during the transfer of data. Here we propose a new improvisation to the TCP protocol that will redefine the way TCP responds to the underlying issues like Route Failures, degraded signal strength, node mobility, etc. during the course of communication. These issues impact the throughput of the network by making the TCP believe that there is congestion in the network and forcing it to invoke the congestion control algorithm.

The proposed protocol is a hybrid derivative of Feedback Scheme Protocol and Adaptive Back-off Response Approach protocol which researchers have developed in the past in silos in the sense that it addresses both scenarios of route failures and packet losses which these two protocols were designed to address independently.

At a conceptual level Feedback Scheme will ensure that route failures are immediately detected and reported back to all the nodes while Adaptive Back-Off Response Protocol will ensure that TCP will ensure that the TCP back-offs from transmitting new packets and retransmit timeout is rather conservatively increased in the event of unacknowledged packets.

In case of a node or link failure, the device that detects it will send RFN to the sender. Based on the Route-Failure-Notifications (RFN), the sender node (whether its originator or intermediary) will be able to re-route the traffic to the next best path. In the meanwhile, the sender will be in a SNOOZE state which means it will preserve its parameters like Congestion Window, Throughput, etc.[27] This will ensure that TCP at the sender end doesn't unnecessarily invoke congestion control mechanism that might slow down the end-to-end throughput.

Since the Ad-Hoc network is extremely mobile and dynamically changes based on routes, signal strength, etc., hence each and every individual intermediary node needs to be self-capable of recovering from packet losses that may not necessarily be due to congestion instead of falling back on the original sender of the packet.

- Whenever a sender node detects packet losses and hence retransmits, it will back-off.
- In the retransmit timeout event the transfer control protocol retransmits the oldest unacknowledged packet and doubles the RTO (retransmit timeout interval). This process is repeated until an acknowledgement (ACK) for the retransmitted packet has been acquired.
- So the RTO (retransmission timeout interval) may be long although the route may have been established again some time ago. This leads to a wasted time. The wasted time can be used to send the packets.
- This wasted time make the RTO (retransmission timeout interval) to rely on a SRTT (smoothed round trip time) which is a weighted average of measured retransmitted timeout.
- The adaptive back off response approach relies on saving the congestion window values, SRTT and slow start threshold when the timer of retransmission expires.
- Instead of multiplying the retransmit timeout interval by two every time it is multiplied by a value known as back off between one and two relying on the final_srtt which is a weighted average of last estimated retransmitted timeout.
- The back off and the new retransmit timeout interval value are evaluated as:

$$Backoff = 1 + \frac{final_{\_srtt}\text{-}\mathrm{min}\_srtt}{(\mathrm{max\_srtt}\ \text{-}\ \mathrm{min}\_srtt)} \qquad (1)$$

$$RTO = Backoff{*}RTO\ present \qquad (2)$$

where RTOpresent is the present value of retransmit timeout, min_srtt is the minimum smoothed round trip time viewed so far and max_srtt is the maximum smoothed round trip time viewed so far.

Thus the new protocol that combines the Feedback and the Adaptive Back-off scheme approaches can be used to improve the TCP performances over Ad-hoc networks by spotting or diagnosing as well as respond to the Out-of-Order instances of packet deliveries that are likely to occur due to the regular changes of routes, signal losses, node failures, etc. as well as provides for an efficient routing algorithm which helps select the most optimal route in terms of throughput.

Simulation Outputs to determine the best combination of Four Protocols discussed above – Feedback Scheme, Adaptive Back-Off, TCP-DOOR, End-to-End Approach

As part of the evaluation of Phase-1 all plausible combinations of Feedback Scheme, Adaptive Back-off, TCP-DOOR, and End-to-End Approach protocol were tested initially. This testing involved a set of 50 nodes for measuring the parameters of Throughput, Packet Delivery Ratio, Signal to Noise Ratio, and End-to-End Delay over a period of time. The objective was to identify the best possible way to mitigate the risk of TCP reducing the throughput by invoking congestion control algorithm in the event of packet losses owing to situations other than congestion such as Node Failure, Link Failure, etc. The following graphs illustrate the outcome of this testing:

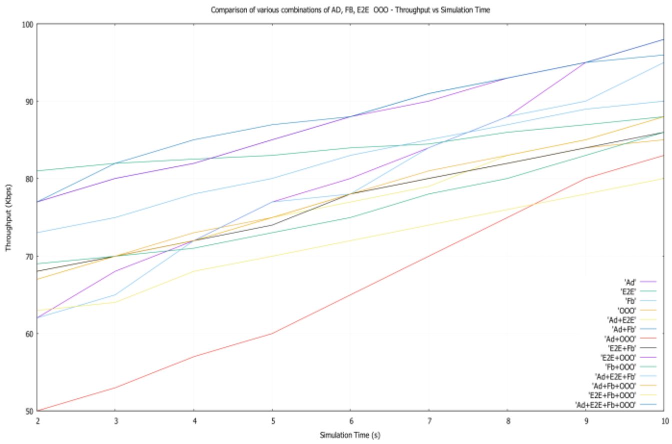


Figure 1: Graph of Throughput plotted for various combinations of Adaptive Back-Off, Feedback Scheme, Out-of-Order Delivery and End-to-End Approach Protocols.

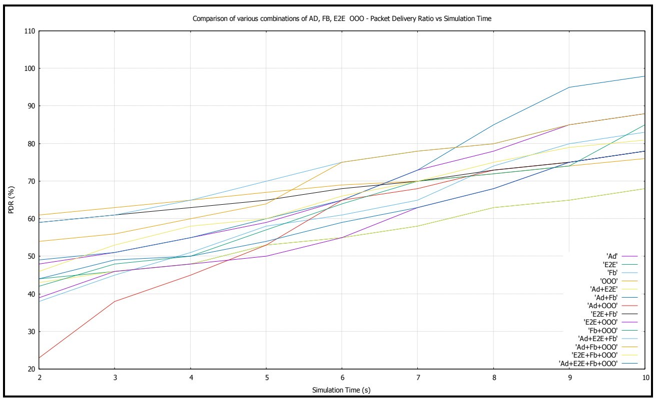


Figure 2: Graph of Packet Delivery Ratio plotted for various combinations of Adaptive Back-Off, Feedback Scheme, Out-of-Order Delivery and End-to-End Approach Protocols.

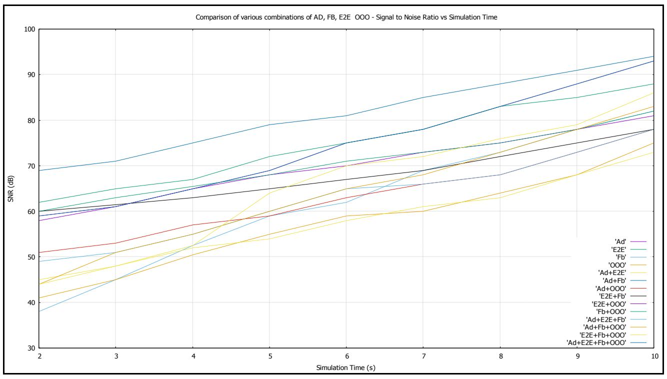


Figure 3: Graph of Signal to Noise Ratio plotted for various combinations of Adaptive Back-Off, Feedback Scheme, Out-of-Order Delivery and End-to-End Approach Protocols.

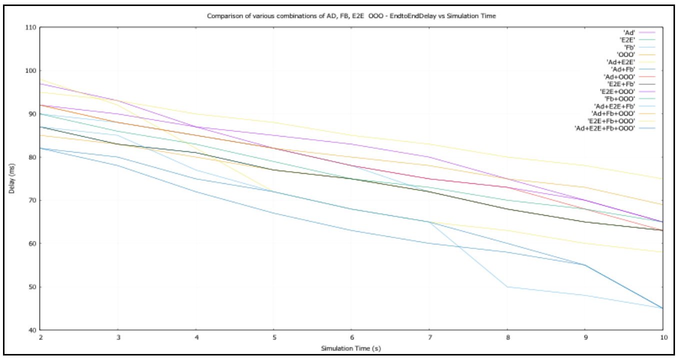


Figure 4: Graph End-to-End Delay plotted for various combinations of Adaptive Back-Off, Feedback Scheme, Out-of-Order Delivery and End-to-End Approach Protocols.

As can be observed from the above graphs, the combination of Feedback Scheme Protocol and Adaptive Back-Off Algorithm outperforms all others since it is able to handle both node failures and packet losses effectively and efficiently compared to others.

Stage 2 of Phase 1: Enhancing the throughput by reworking congestion window

The working principle of the second stage is described as follows:

To immune the two end-points (Sender and Receiver) from the unpredictable behavior of the intermediate Ad-Hoc Networks, it will modify the TCP congestion window to implement the HS-TCP as described in RFC-3649 (or its variant, depending on link quality) which will ensure that in the eventuality of any back-off being forced on sender, the back-off time is minimal and recovery is extremely fast to ensure end-to-end faster performance of TCP. Thus as a next step to this testing, the underlying transport stack of TCP was manipulated in terms of congestion window by changing the TCP to HSTCP as defined in the RFC 3649 and also to MX-TCP wherein Congestion Window is reduced to Zero. Following graphs illustrate the output of this testing which was done only for the combination of Feedback Scheme and Adaptive Back-Off Algorithm that outperformed others as described in the earlier section of above Phase 1 of Section ‘Discussions and Results’.

Simulation Outputs after applying HSTCP / MXTCP to the combination of Feedback Scheme and Adaptive Back-Off

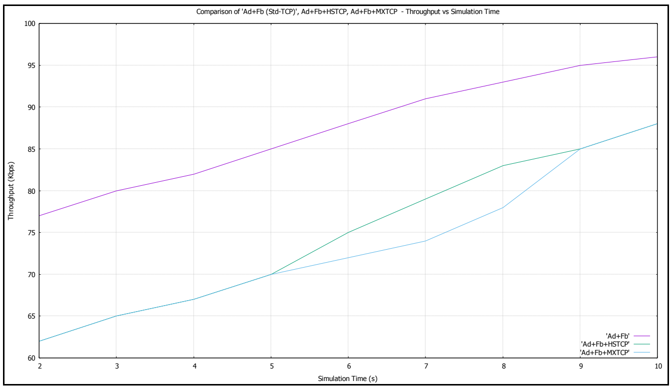


Figure 5: Graph of Throughput plotted for comparing combination of Adaptive Back-Off and Feedback Scheme with Standard TCP against HSTCP and MXTCP.

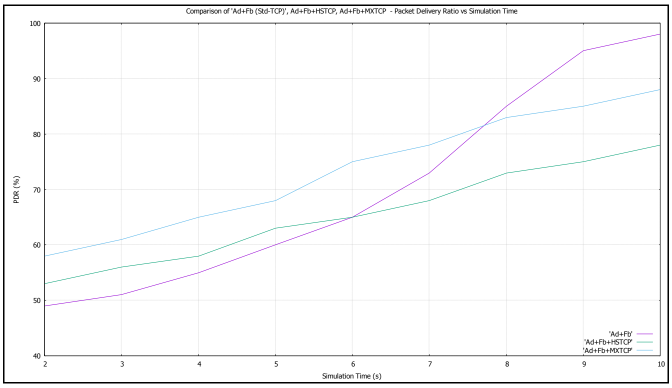


Figure 6: Graph of Packet Delivery Ratio plotted for comparing combination of Adaptive Back-Off and Feedback Scheme with Standard TCP against HSTCP and MXTCP.

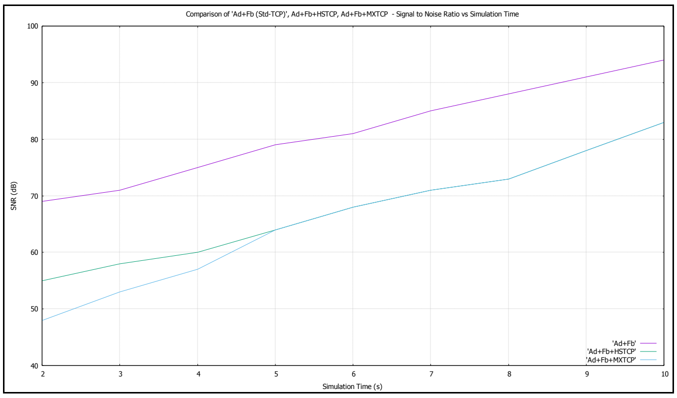


Figure 7: Graph of Signal to Noise Ratio plotted for comparing combination of Adaptive Back-Off and Feedback Scheme with Standard TCP against HSTCP and MXTCP.

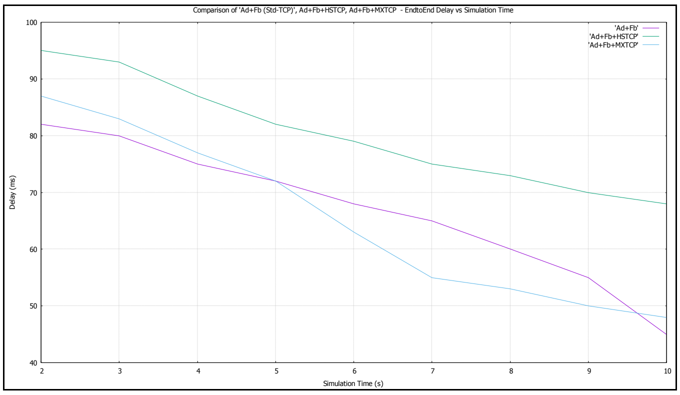


Figure 8: Graph of End-to-End delay plotted for comparing combination of Adaptive Back-Off and Feedback Scheme with Standard TCP against HSTCP and MXTCP.

The proposed two stage protocol can also address the issue of TCP slow start after back-off that may help to prevent it from congesting the entire network since the recovery is being attempted at individual node where losses / failures occur instead of end-points. Finally, the performance of this proposed algorithm is established by measuring the Throughput, Packet Delivery Ratio, Delay and Signal-to-Noise ratio is also a critical parameter since it is extremely important for the correct data to be delivered which can be determined by using Frame-Check-Sequence. As is seen from the above graphs, modifying the congestion window of TCP based on the underlying network conditions have helped overcome the basic limitation of TCP in Ad-Hoc networks wherein TCP cannot differentiate between packet losses due to network congestion and packet losses due to node / link failures or losses. It was clear from the above that the modified congestion control mechanism for TCP definitely outperformed the standard TCP in MANETs.

2. Phase-2: Solution for determining the most optimal path from Source to Destination adaptive to changing network dynamics (called "Adept Route Yielding Algorithm")

The working principle of the phase 2 of this proposed protocol is as described below:

Ad-Hoc Networks are highly dynamic, frequently changing and of indeterministic nature since we can never predict the number of hops / nodes it might take for a packet to traverse before reaching its intended destination. As discussed earlier in Phase-1, all the nodes will discover each other in the Ad-Hoc Network and use standard routing protocols like AODV, DSR, etc. to build the possible neighbor relationships. Once the likely neighbors are identified, the proposed enhancement will kick-in to identify and select the most optimal path in terms of throughput once all the possible paths from Source to Destination are identified. Hence each node in the network will attempt to discover the most optimal path to forward the packets based on the following parameters:

- Distance / Number of hops to reach that node
- Mobility of Nodes / Link Lifetime
- Delay / Latency
- Bandwidth (‘Line Rate to be precise) between two nodes

The step by step execution is as follows:

a. The paths that are either directly connected or at the maximum one hop away are expected to be more stable with superior connectivity compared to remote nodes. Additionally, the smaller the number of hops means lesser possible points of failure. Hence the algorithm will limit the consideration of paths to nodes either directly connected or at maximum one hop from directly connected node. Below figure illustrates the meaning of directly connected and one hop distance from directly connected nodes.

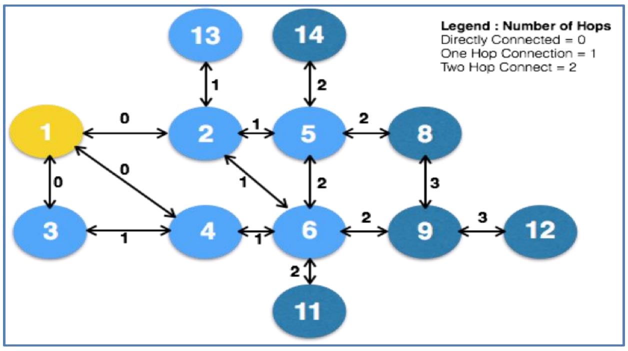
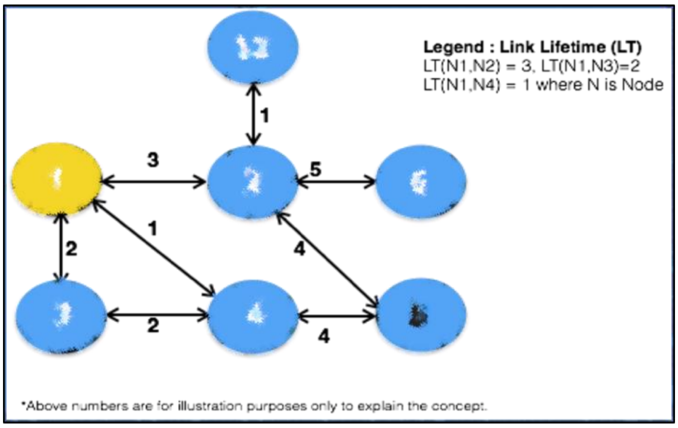


Figure 9 : Sample Topology

In the above figure 9, considering 1 as base node:

- Directly connected Nodes of 1: 2, 3, 4
- Nodes One-Hop from Directly Connected is as per below:
  - One-hop from Node 2 : 5, 6, 13
  - One-hop from Node 3 : 4
  - One-hop from Node 4 : 3, 6

b. The node with lesser mobility and distance is certainly expected to have higher link lifetime as mentioned in earlier point. Link lifetime depends on both node lifetime and connection lifetime. Hence, next we propose to consider only those links having lifetime better than or equal to the average lifetime of all links under consideration at the given node.



*Above numbers are for illustration purposes only to explain the concept.

Figure 10: Topology highlighting Link Lifetime

In the above figure, the numbers on the connectors between two nodes are indicative of the connection lifetime – bigger the number, longer is the lifetime. Here we are considering the directly connected nodes only for lifetime as considering the nodes one-hop away from directly connected will be dependent on their connectivity to the directly connected node.

- So, again considering 1 as base node, we compute the lifetime of all the directly connected nodes i.e. 2, 3 & 4.
- Lifetime of each of these connections is
  - Node 1 to Node 2 : 3
  - Node 1 to Node 3 : 2
  - Node 1 to Node 4 : 1
  - Hence average of the three is : (3+2+1)/3 = 2

Thus we will only shortlist Link (1,2) and Link(1,3) since lifetime is >=2 and discard Link(1,4)

c. Availability of higher bandwidth is imperative for the data to be transferred at a higher rate. However, if the bandwidth between two nodes is high and at the same time the latency between them is also high, the high latency will adversely impact the throughput on the link. If Lifetime of both links is same and Line Rate and Latency are also same, then the both paths are same quality and hence by default first path is selected. However, this is rarely the scenario as either or all of these parameters could be different. Hence an optimal combination of Latency and Bandwidth is extremely critical measure for determining the performance of a link or route. Hence we finally propose to compute the Bandwidth Delay Product equivalent (which is product of line rate and one-way latency) for the links under consideration. This can be computed, for the sake of simplicity, using bandwidth configured (line rate) on the transmitting interface and the Round-Trip-Time (RTT) computed from the RREQ and RREP messages.

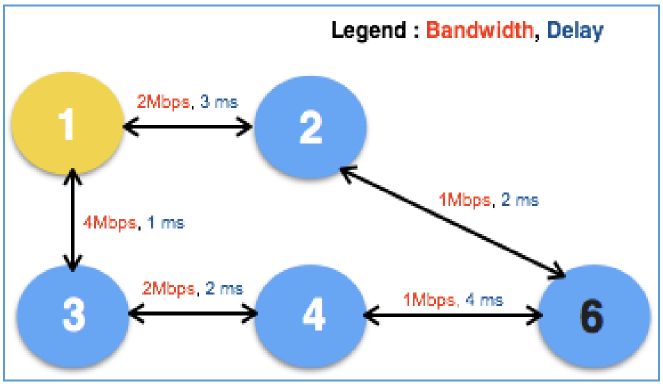


Figure 11: Topology illustrating bandwidth and delay

In the above figure, we compute the bandwidth and delay product for each pair of nodes. Here, for simplicity sake, we have indicated the bandwidth & delays. For Example: BDP Link (1,2)= 2Mbps x 3ms = 750 bytes. We thus calculate BDP for all paths under consideration in this manner. The next step is to shortlist and select the maximum of best 2 links based on highest BDP, say L1 & L2. Now following steps help identify the better of the 2 links:

- If BDP(L1) is equal to BDP(L2), then link with lower RTT is selected.
- If BDP(L1) is greater than BDP(L2), then L1 is the preferred path if its latency (or RTT or Delay) is less than or equal to L2
- If BDP(L1) is greater than BDP(L2), but the RTT1 is also greater than RTT2, then the link with BDP value closest to rcwnd (Receiver buffer) is selected.

d. Considering that the MANETs may have asymmetric paths, this algorithm will be executed at every node in bidirectional mode. Limiting the number of hops to a maximum 2 and utilizing the already available values of Bandwidth and RTT, the overheads in computing BDP are expected to be minimal while trying to select the most optimal path in terms of throughput on the network.

Thus to summarize, the above work not only ensure an optimal performance of TCP by providing immunity to the Sender and Receiver from intermediate network, it also attempts to isolate the end-to-end performance from uncertainties created by intermediary nodes in Ad-Hoc networks.

Simulation output of the Proposed Adept Route Yielding Algorithm (ARYA) applied to results of above section 2 of Phase A of Discussions and Findings:

To maintain consistency, the simulation for this enhancement in routing algorithm was also tested in NS2 Simulator with graphs being plotted in GNUPLOT tool. The results were validated for consistency using OMNET++ to ensure simulator agnostic nature of the proposed algorithm. The below Figures 12 thru 15 show the comparative results of plotting combination of Feedback Scheme and Adaptive Back-Off algorithm with TCP Stack modified as HSTCP / MXTCP and the change experienced when ARYA is applied to it.

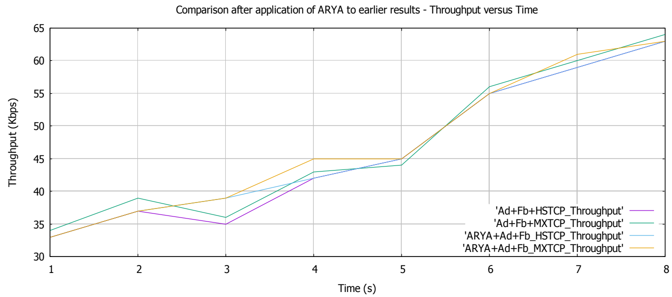


Figure 12: Graph of Throughput Statistics plotted to show comparison of Combination of Adaptive Back-Off and Feedback Scheme with HSTCP/MXTCP and the changes in their behaviour when ARYA is applied to it.

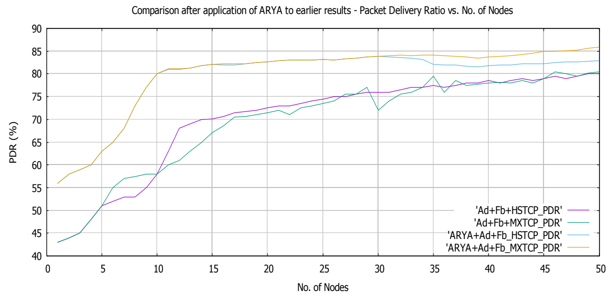


Figure 13: Graph of Packet Delivery Ratio plotted to show comparison of Combination of Adaptive Back-Off and Feedback Scheme with HSTCP/MXTCP and the changes in their behaviour when ARYA is applied to it.

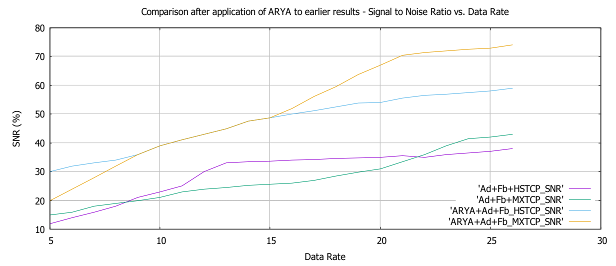


Figure 14: Graph of Signal to Noise Ratio plotted to show comparison of Combination of Adaptive Back-Off and Feedback Scheme with HSTCP/MXTCP and the changes in their behaviour when ARYA is applied to it.

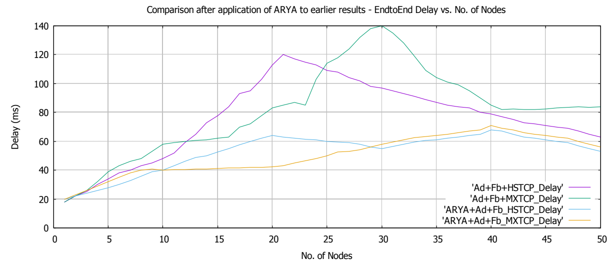


Figure 15: Graph of End-to-End Delay plotted to show comparison of Combination of Adaptive Back-Off and Feedback Scheme with HSTCP/MXTCP and the changes in their behaviour when ARYA is applied to it.

Thus the above graphs effectively establish the efficiency of the Adept Route Yielding Algorithm and overall Feedback-based Adaptive Speedy TCP to improve the performance of TCP over MANETs.

RESULTS AND CONCLUSION

It was clear from the above that the modified congestion control mechanism for TCP definitely outperformed the standard TCP in MANETs. Similarly, this modification in congestion control window when deployed together with the modification in existing MANET routing protocols far outperformed the Standard TCP deployed in a conventional way. For the current work, we have used NS2 as the primary simulation tool, but the same results can be achieved by other Network Simulation tools including but not limited to NS3, Modeler, etc. This research initially changes the underlying behavior of TCP to HS-TCP based on the observed network conditions of delay (latency) and bandwidth. The observed results also reflected that the concept of combining HS-TCP together with a combination of adaptive and feedback approach gave superior results on all three parameters of Delay, Throughput and Delivery Packet Ratio when compared to the existing traditional approaches. The fact that the proposed changes in protocols have been observed to consistently outperform the traditional approaches on all parameters in consideration, this approach can bring in the much desired performance stability for any device that needs to be connected to the network giving a guaranteed consistently performing connectivity. Further these observations were revalidated using other tools like OMNET++ to make the findings platform agnostic and conclusive before planning for real world adoption. Though the given protocol methodology has been designed for MANET, with nil to minimal changes, it can be well adopted to any kind of network.

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