

Performance of TCP over Different Routing Protocols in Mobile Ad-Hoc Networks

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Abstract—TCP/IP is the standard networking protocol on the internet and is also the most widely used. Due to these reasons, its use over Mobile Ad-Hoc networks is a certainty. Ad-Hoc networks are prone to link failures due to mobility. TCP is unable to distinguish between losses due to route failures and losses due to congestion. As a result, throughput degrades significantly when nodes move. It is therefore essential to study how TCP performs over ad-hoc networks. We have used simulations in the cmu extension to *ns* to analyse the performance of TCP Tahoe over a set of routing protocols including the Signal Stability Adaptive routing protocol which we have implemented in *ns-2*. We identify characteristics in each of these routing protocols that determine the behaviour of TCP over them.

Keywords: Ad-Hoc Networks, Routing Protocol, Throughput, Pause Time, Mean Speed

I. Introduction

With the ever increasing demand for connectivity the need for mobile wireless communication is inevitable. The use of portable laptops and hand held devices is increasing rapidly. Most of the portable communication devices have the support of a fixed base station or access point that corresponds to the last-hop-wireless model. This trend can be observed in wide-area wireless cellular systems. However, such a support is not available in settings where access to a wired infrastructure is not possible. Situations like natural disasters, conferences and military settings are noteworthy in this regard. This has led to the development of *Mobile Ad-hoc Networks* [1].

An Ad hoc network is a dynamically changing network of mobile devices that communicate without the support of a fixed structure. There is a direct communication among neighbouring devices but communication between non-neighbouring devices requires a routing algorithm. A lot of work has been done on routing protocols since they are critical to the functioning of ad-hoc networks. Various routing protocols have been proposed in the literature such as the Destination Sequenced Distance Vector (DSDV) [2], Ad-hoc On-demand Distance Vector (AODV) [3], Dynamic Source Routing (DSR) [4] and Signal Stability based Adaptive (SSA) Routing [5].

TCP/IP is the standard networking protocol on the internet. It is the most widely used transport protocol for data services like file transfer, email and WWW browser. Due to these reasons, its use over mobile ad-hoc networks is a certainty. TCP, primarily designed for wireline networks, faces performance degradation when applied to the ad-hoc scenario. In addition, variants of TCP behave differently over various routing protocols. It is essential to understand how TCP performs over ad-hoc networks. In this paper, we have done a performance analysis of TCP over a set of ad-hoc routing protocols, i.e., DSR, DSDV, AODV and SSA.

The paper is organised as follows. Section II presents an overview of the ad-hoc routing protocols that we have analysed. Section III describes the simulation methodology. In Section IV, an analysis of the simulation results is presented. Section V concludes the paper and finally Section VI suggests direction for future work.

II. Overview of Ad-hoc Routing Protocols

We now discuss the various routing protocols in brief. Dynamic Source Routing employs [4] *source routing* wherein the source determines the complete sequence of nodes through which a packet is to be routed. Whenever a source has a packet to transmit, it checks its routing table for a route to the destination. In case a route is not found then a route request broadcast is initiated. On receiving this request, each node again broadcasts this request by appending its address to the request packet until this packet reaches the destination. The destination replies to the first request that reaches it. It sends a route reply to the source containing the route from the source to the destination. When this packet reaches the source a connection is established and all subsequent packets contain the complete route in the packet header. No routing information is maintained at the intermediate nodes. When the data

link layer at a particular node encounters a transmission failure, it issues an error notification to the source and a new route search is initiated.

In Destination Sequenced Distance Vector routing [2], each node maintains a routing table wherein the next-hop information for each reachable destination is maintained. Every node in the network periodically broadcasts its routing table with monotonically increasing sequence numbers. An update is done using the Bellman-Ford algorithm. A broken link can be detected if no broadcasts have been received from the node for a while. On detection of a broken link, all routes passing through that hop are assigned an *infinity* metric.

Ad-Hoc On-demand Distance Vector routing [3] algorithm borrows its salient features from DSR and DSDV. When a source needs a path to the destination, it broadcasts a route request message enclosing a monotonically increasing *broadcast_id* and the last known sequence number to that destination. The route request is broadcast until it reaches a node that has a route to the destination with the destination sequence number higher than that enclosed in the request. A route request propagating through the network establishes the next-hop information for the reverse route to the source. A route reply generated by the destination propagates along the reverse route and establishes the forward route information at the intermediate nodes. Each node records only the next hop for a destination and not the entire route as done in source routing. Routing table information in AODV is restricted to the active nodes. A neighbour is considered active if it originates or relays at least one packet for the destination within the most recent *active_timeout* period. Failure of a link can be detected via hello messages or link layer detection. When a link goes down, the upstream nodes are notified of the failure that destination is marked as unreachable in the routing tables of these nodes.

In Signal Stability based Adaptive routing [5], every node maintains a Routing Table wherein the destination and the next hop information is stored. Along with this, a Signal Table is also maintained where a record of the neighbours is kept and they are classified as strongly or weakly connected. This is done on the basis of periodic link layer beacons received by a node from its neighbours. The SSA protocol uses the stability of links as a route selection criterion. When a source has data to send to a destination, for which there is no entry in the route cache, it broadcasts route search packets to its neighbours. The nodes receiv-

ing these packets broadcast the route search if it is received from a strongly connected neighbour and the request has not been propagated previously. When a host moves out of the range of its neighbours or shuts down, the neighbours recognize that the host is unreachable. The routing table and the signal table are accordingly modified and a route error packet is sent to the source. On receiving this error notification the source initiates a new route search.

III. Simulation Methodology

In this paper, we have used simulations to study the performance of TCP over ad-hoc routing protocols. We have carried out the simulations in Network Simulator (*ns-2*) from Lawrence Berkeley National Laboratory (LBNL) [10] with extensions from the MONARCH Project at Carnegie Mellon University [11].

At the physical layer, the extended *ns* employs a radio propagation model supporting propagation delay, omni-directional antennas, and a shared media network interface. The IEEE 802.11 Medium Access Protocol is employed at the Link Layer level. We have extended *ns-2* for modelling the SSA protocol. The motivation behind this is that SSA is the only protocol among these that considers the stability of a route.

For the performance analysis of the routing protocols we have simulated a scenario of 25 nodes moving in a rectangular topology of 1500m x 300m, with each node having a transmission range of 250m. All nodes communicate with identical wireless radios, which have a bandwidth of 2Mbps. The simulations are run for a period of 200 seconds. Each simulation is run over 50 different mobility scenarios.

We have employed a single TCP traffic source in each simulation. The version of TCP used is TCP Tahoe with fast retransmit [12]. The nodes in the simulation move according to the 'random waypoint' model. Each scenario is characterised by a pause time that varies randomly between $0.9p - 1.1p$ where 'p' is the mean pause-time value specified at the time of the scenario file generation. At the start of the simulation, each node waits for a pause time. It then randomly selects its destination and moves towards this destination with a speed randomly lying between $0.9v - 1.1v$ where 'v' is the specified mean speed. On reaching this destination it pauses again and repeats the above procedure till the end of the simulation. The simulations are run for mean speeds of 2, 6, 10, 15 and 20 m/s and pause times of 0 and 10 seconds (50 scenarios).

for each mean speed and pause time specification).

The amount of data transmitted by a TCP source per unit time has been chosen as our performance metric. Node mobility is characterised by the average node speed and the average pause time of the nodes. We monitor the above metric as a function of *mean node speed* and *pause time* to assess the ability of a routing protocol to adjust to changing node mobility.

IV. Simulation Results

In Figure 1, 2 and 3, we show the variation of TCP Tahoe Throughput versus mean speed of nodes for a pause time of 0, 10 and 20 seconds respectively. As can be seen, the throughput decreases with increasing mean speed of nodes. Increasing mean speed results in higher mobility and hence the frequency of route failures increases. Due to route failures TCP traffic suffers packet losses which are interpreted as signs of congestion and as a result TCP shrinks its transmission window. Moreover, a delay has to be incurred to search for a new route. All this results in degradation of the TCP throughput.

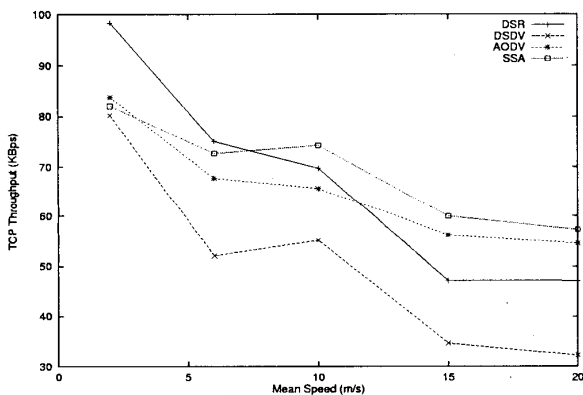


Fig. 1. TCP Tahoe Throughput versus Mean Speed; Pause Time = 0 sec

DSDV performs the worst among all the protocols. Since DSDV is a table driven protocol, the routing table at every host maintains exhaustive information about the network topology. The adaptation to the dynamically changing network is associated with large routing overheads. An on-demand protocol, on the other hand, searches for a route whenever a need arises for it. Thus, all the on-demand protocols outperform DSDV irrespective of the mobility rate.

DSR has virtually no overheads at low speeds because it is an on-demand protocol and there are no periodic exchanges between the nodes. Thus, at low

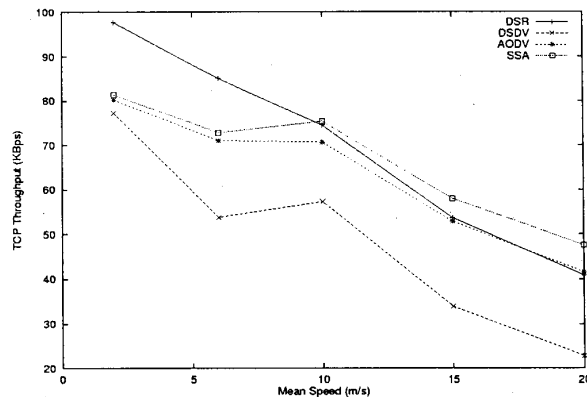


Fig. 2. TCP Tahoe Throughput versus Mean Speed; Pause Time = 10 sec

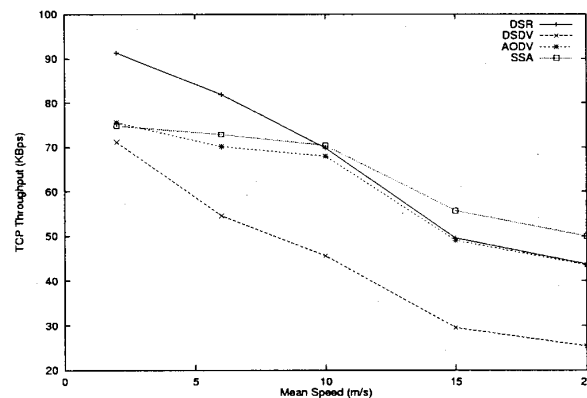


Fig. 3. TCP Tahoe Throughput versus Mean Speed; Pause Time = 20 sec

speeds, DSR outperforms other protocols (see Figure 1, 2 and 3). DSR maintains all entries (active and inactive) in its route cache. At high mean speeds, the routes in the route cache can go stale with a fairly high frequency and erroneous routes may get formed via route searches initiated by the source [8]. Also, DSR has no concept of sequence numbers and therefore the staleness of the route cache may lead to routing loop formation. These can lead to degradation of TCP throughput especially at high mean speeds.

In AODV, efficacious route cache management is done via a cache entry timeout that ensures that only active routes are maintained in the route cache. This prevents the problem of a stale route entry in the route cache. Also, the use of sequence numbers prevents the formation of routing loops. Hence the throughput degradation with increasing mean speed in AODV is fairly small (see Figure 1, 2 and 3).

The route establishment in SSA is done through strongly connected hosts. SSA chooses a route based on its stability. Hence, the route failures at high mobility are less frequent than any other protocol. Due to this, SSA outperforms DSR, DSDV and AODV (which have no consideration for stability of a route) at high mean speeds. The link strength assessment and the use of hello messages constitute additional overheads due to which SSA does not perform well at low speeds.

From the results obtained, we infer that frequency of route failures, routing overhead and delay in route establishment are the key features that affect TCP throughput in an ad-hoc network. A previous work [9] highlighted the importance of route length in determining the performance of TCP. Thus, a routing protocol that searches for shorter as well as stable routes would perform well. DSR, AODV and DSDV prefer shorter routes whereas SSA chooses stable routes. The stability of the routes becomes even more crucial at high mobility as can be seen from SSA's performance at high mean speeds.

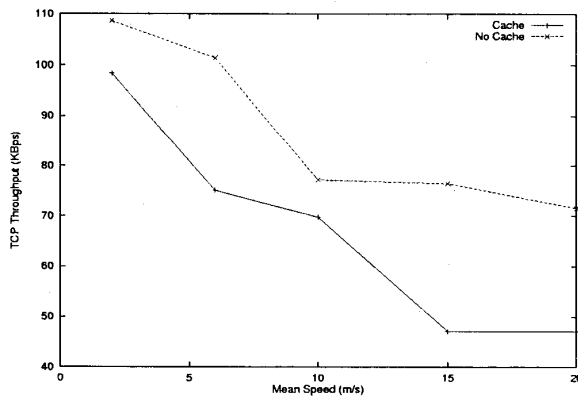


Fig. 4. TCP Tahoe Throughput versus Mean Speed over DSR with cache replies and without cache replies

There are some features of routing protocols that play a major role in determining their performance. The prominent one among these are the use of route cache in DSR and location stability in SSA. We have varied these features and analysed the effects of these on the performance of TCP. In Figure 4, TCP throughput is measured as a function of mean speed of the nodes with DSR as the underlying routing protocol. A comparison of DSR with route replies from cache and without route replies from cache is done. There is a significant improvement in the TCP throughput when the route replies from cache are disabled (see Figure

4). As noted before, this is due to the problem of stale entries in the route cache at the intermediate nodes. A detailed analysis of this observation has been presented in [8].

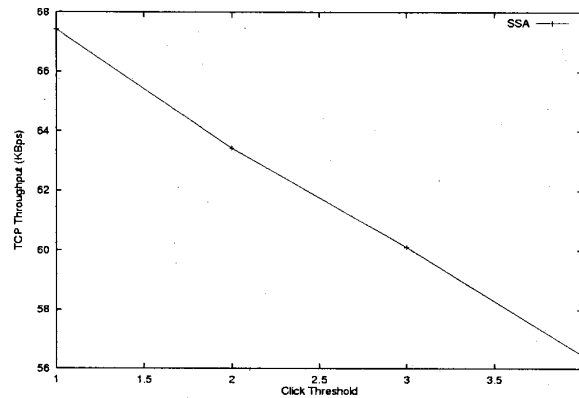


Fig. 5. TCP Tahoe Throughput versus *click_threshold* over SSA, Mean Speed = 6 m/s, Pause Time = 0 sec

In SSA, every node classifies its neighbours as “strongly” or “weakly” connected. This classification is done on the basis of signal strength information of the packets received from the neighbours. A *click* for a neighbour is recorded if in a time quantum a beacon has been received with a strong signal from the neighbouring host. If the number of clicks exceed a *click_threshold* value then the neighbour is recognised as a strongly connected neighbour. In Figure 5, the TCP throughput is plotted as a function of varying *click_threshold* values with fixed mean speed and pause time of the nodes. We find that SSA with location stability performs worse than without location stability. This is because location stability places a much stronger condition on the choice of a route as strongly connected. If SSA is unable to find a strong route, route discovery takes longer time and hence TCP throughput degrades. So location stability should be cautiously used in conjunction with SSA protocol.

V. Conclusion

Over the past few years, a variety of routing protocols have been proposed for Mobile Ad-Hoc Networks. However, little work has been done to study the performance of TCP traffic over these protocols. We have analysed the performance of TCP over these protocols using simulations in *ns*. We have modified the *ns* network simulator to include the SSA routing protocol. We simulated each protocol in ad-hoc networks consisting of 25 mobile nodes and presented the results for

a range of node mobility rates and movement speeds. We have identified some features of routing protocols that affect the TCP performance. We have also examined the performance of TCP by varying specific key parameters of some routing protocols. We believe that this is one of the first work that presents a performance based comparison of TCP over different adhoc routing protocols.

VI. Future Work

We have simulated an Ad Hoc network for a single TCP traffic source. We believe that it would be interesting to see the performance of the routing protocols with multiple traffic sources. Since TCP performance is closely coupled with the stability and length of the routes in ad-hoc networks, more work needs to be done to develop a routing protocol that takes these into consideration when choosing a route. We intend to do an extensive study that incorporates new routing protocols and variants of TCP.

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