LINK CONNECTIVITY ASSESSMENT BASED APPLICATIONS FOR MOBILE AD-HOC NETWORKS

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ABSTRACT

Owing to the absence of any support structures, ad-hoc networks are prone to link failures. In such a dynamic environment the assessment of link connectivity can help alleviate the mobility-induced mal-effects. This paper discusses the applications of residual-link-lifetime appraisal. Herein we propose an optimal route discretion policy, effective route cache management technique and dynamic power adjustment scheme.

Key words: Ad-hoc networks, Signal Strength, Affinity, Pause Time, Mean Speed, Throughput.

1. Introduction

The demand for easy maneuverability and portability of the integrated computing and communication devices has spurred the need for mobile wireless communication. The use of portable laptops and handheld devices is increasing rapidly. Most of the portable communication devices have the support of fixed base stations or access points and predesignated routers. This conforms to the last-hop-wireless scenario. This trend can be observed in wide-area wireless cellular systems and Bluetooth. However, such a support is not available in settings where access to a wired infrastructure is not possible. Situations like natural disasters, conferences, military settings are noteworthy in this regard. This constitutes the motivation for mobile ad-hoc networks [1]. A mobile ad-hoc network is a dynamically changing network of mobile devices that communicate without the support of fixed base stations. The neighbouring devices can communicate directly, but the non-neighbouring ones can do so only through the intermediate mobile hosts. Owing to the inherent mobility in ad-hoc networks, a robust and intelligent routing strategy is needed to adapt to the network dynamism. A number of routing protocols have been proposed in literature. The Destination-Sequenced Distance Vector (DSDV) [6] routing protocol maintains an exhaustive account of network topology in a routing table, which is updated in accordance with the dynamic changes in the topology. The Dynamic Source Routing [4] and Ad-Hoc On Demand Distance Vector (AODV) routing [5] are on demand protocols, i.e., in these protocols the routes are established on data transmission demand by a source host. Given a network topology, none of these protocols select a route based on stability. In DSR and AODV routing protocols, the route request that reaches the destination first is accepted without an estimation of the time for which this route will last. This route may contain weak links and the frequent route failures that can ensue, affect the throughput adversely. The Signal Stability Adaptive (SSA) routing protocol [2] uses the stability of individual links as the route selection criterion. Each node classifies its neighbours as strongly/weakly connected on the basis of link layer beacons that are exchanged periodically. This assessment of network connectivity is however, quite qualitative. The destination chooses the route in the first arriving request, since this route is probably shorter and less congested. However this may not be the longest lasting route. The link connectivity assessment of a mobile host vis-à-vis its neighbours can be used for some interesting applications including an optimal route selection strategy. The criterion for link connectivity is the time for which the link is up. Such an 'affinity' parameter has been proposed in [3], which characterizes the strength and stability of link connectivities. The affinity between two nodes n and m, A_{nm}, is the prediction of the lifetime of the link L_{nm}. The affinity, A_{nm}, is the time taken by a node n to move out of the transmission range of node m. Node m samples the strength of periodic signals received from node n. The rate of change of signal strength is given as,

$$\Delta S_{nm} = \frac{S_{nm\,(current)} - S_{nm\,(prev)}}{\Delta(t)}$$

where Δ(t) is the time elapsed between the Snm (current) and Snm(prev) values assessed by the node. This is averaged over last few samples to obtain $\Delta S_{nm(avg)}$. The affinity Anm is now calculated as,

$$A_{nm} = \begin{cases} high & \text{if } \Delta S_{nm\,(avg)} > 0 \\ \dfrac{S_{thresh} - S_{nm\,(current)}}{\Delta S_{nm\,(avg)}} & otherwise \end{cases}$$

where S_{thresh} is the threshold signal strength below which a link L_{mn} can be assumed to be disconnected.

The affinity appraisal can be used for enhancement of the ability of an ad-hoc network to adapt to the network mobility. A routing strategy has been suggested in [3] that conforms to this application. On the propagation of a route request by a source host, the successive values of affinity are added onto the route request packets. The destination examines the minimum affinity, A_{min} along all such routes that reach the destination. The route that has the highest value of A_{min} is finally selected by the destination.

The affinity evaluation can be utilized to develop an effective route cache maintenance strategy. A mobile host maintains a record of the routes that it has been able to learn, in a route cache. Routing protocols like the DSR suffer from the problem of the prevalence of routes in the cache that go stale due to node mobility. We propose an affinity based route cache timer that alleviates the problem of stale routes.

In an ad-hoc network, battery power conservation strategies can obviate the need for large batteries and frequent battery replacements. Dynamic adjustments in the transmission power of the mobile hosts can also be done on the basis of affinity estimation.

The rest of the paper is organized as follows. Section 2 presents a residual-route-lifetime assessment based routing protocol. Section 3 describes affinity based route cache timeout mechanism. Dynamic power adjustment scheme is discussed in section 4. Section 5 concludes the paper and scope for future work is presented in the final section.

2. Residual-Route-Lifetime Assessment Based Routing Protocol

In this section, we propose a new routing protocol based on route-lifetime assessment via affinity appraisal. The following subsections deal with protocol description, protocol implementation and simulation results.

2.1 Protocol Description

When a source has some data to be transmitted, it initiates a route request. The route establishment is done by broadcasting route request packets that contain a sequence number, source id and destination id. An intermediate host listening to the route request broadcasts the request further after appending the affinity of the link via which it received the packet. This node does not entertain any further requests with the same <sequence number, source id>. This process continues until the request reaches the destination. After receiving the first request, the destination waits for a fixed time interval for more route requests to arrive.

If the desired data transmission pertains to Constant Bit Rate data then the route selection is done as follows. For each of the candidate routes that reach the destination, the destination determines the weakest link affinity A_{min}.

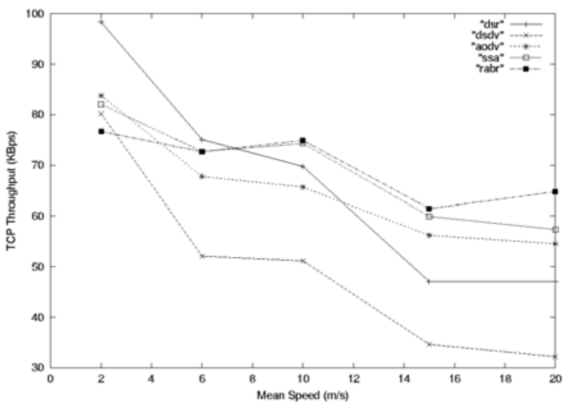

Fig 1: TCP Tahoe Throughput vs Mean Speed; Pausetime = 0 s.

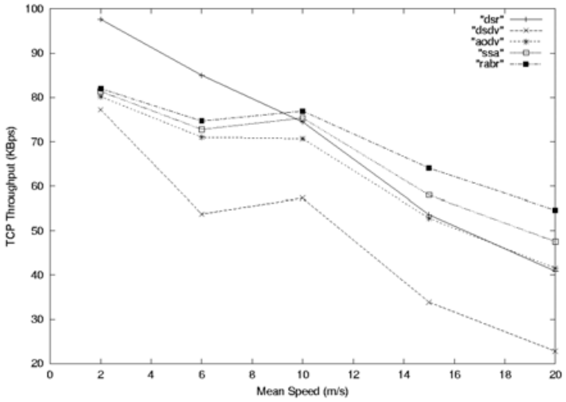

Fig 2: TCP Tahoe Throughput vs Mean Speed; Pausetime=10 s.

A_{min} qualifies the route lifetime. The route that has the maximum value of A_{min} is then selected by the destination. Hence, the most stable route is chosen for data transmission.

In TCP, the throughput is a function of the hop length of the route. Hence, an optimal route selection should be based on the appraisal of the weakest link affinity and the number of hops of the candidate routes. For the various candidate routes, the destination node determines the weakest hop affinity A_{min} and gauges the throughput t_n by determining the hop length, n. The mapping of n to t_n is known apriori [7].

The number of bytes Bi that can be transmitted along a ith route before route failure, is given by,

$$B_i = t_i * A_{min}(i)$$

The destination selects the route that has the maximum value of the parameter 'B'. For any any two routes i and j, the i^{th} route is preferred if $B_i > B_j$. If $A_{min}(i) < A_{min}(j)$, then the preference for the i^{th} route is justified because the route pertains to a greater throughput in the present context. Now consider the case when $A_{min}(i) > A_{min}(j)$. Although the i^{th} route is a longer lasting route, this might correspond to a lesser throughput in the present context. However, this route is capable of transmitting more bytes Bi in the anticipated life time $A_{min}(i)$ and hence is expected to be followed by lesser number of route breakages during a data transmission session requiring certain number of bytes to be transmitted. Hence, lesser route re-establishment delays may lead to a better throughput for the i^{th} route.

Each node uses link layer detection to infer the status of the link. If link failure occurs during a data transmission session, the source is informed of the failure via a route error packet. On receiving a route error packet the source initiates a new route search and generates an erase packet that purges the next hop entry at the nodes between the source and the node after which the route has failed. Also, the source queues subsequent packets for that destination until a new route is found. If no route is found after a few tries, then these packets are broadcast in the network.

2.2 Protocol Implementation

The protocol proposed by the authors has been integrated with the Lawrence Berkeley national Laboratory network simulator, ns with extensions by the Monarch project in the Carnegie Mellon University [8].

For the performance analysis of the protocol we have simulated a scenario of 25 mobile hosts, moving in a rectangular topology of 1500m x 300m, with each host having a transmission range of 250m. The simulations have been run for 200 s. The performance analysis of ad-hoc routing protocols has been done vis-à-vis CBR and TCP data sources.

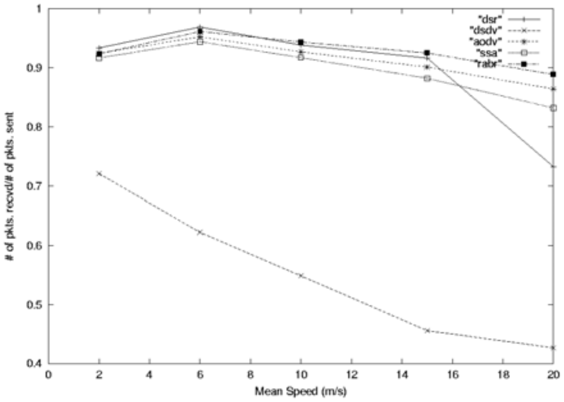

Fig 3: No. of Packets recvd./No. of Packets trans. Vs Mean Speed; Pausetime=0s.

The nodes in the simulations move according to the 'random waypoint' model. Each scenario is characterized by a pause time that varies randomly between 0.9p – 1.1p where 'p' is the mean pause time. At the start of the simulation, each node waits for a pause time. It then randomly selects its destination and moves towards it with a speed randomly chosen between 0.9v – 1.1v where 'v' is the mean node speed. On reaching the destination, it pauses again and repeats the entire procedure till the end of the simulation. The performance analysis of the routing protocols has been done for mean speeds of 2, 6, 10, 15 and 20 m/ s and pause times of 0 and 10 seconds.

2.3 Simulation Results

Figures 1 and 2 depict the relative performance of RABR (Route-Lifetime Assessment Based Routing), SSA, DSR, DSDV, and AODV for TCP senders. For CBR senders, the results are shown in figures 3 and 4. As expected, the performance of all protocols degrades with increasing mean speeds and decreasing pause times. It is observed that the protocol proposed by the authors outperforms all protocols at large mean speeds. Although DSR performs the best at low speeds, the performance of the RABR is comparable to other protocols.

Backed by an ingenious affinity based route selection mechanism, the RABR protocol adapts well to the increasing network mobility.

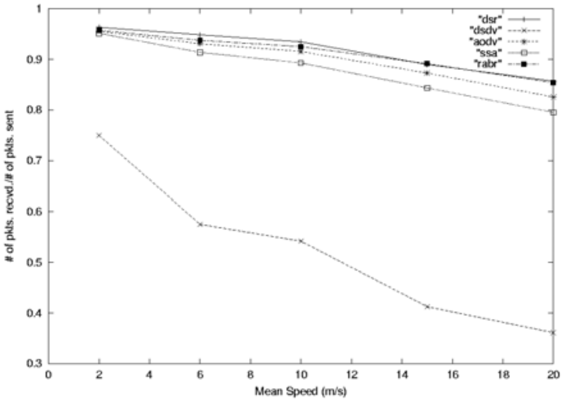

Fig 4: No. of Packets recvd./ No. of Packets trans. Vs Mean Speed; Pausetime=0s.

Other protocols in which the route enclosed in the first route request packet is selected for data transmission, have to face a substantial throughput degradation. RABR chooses the longest lasting route for CBR agents, thus ensuring lesser route failures as compared to other protocols. For TCP sources, the combination of stable and shorter routes ensures better throughput even at high mobilities.

4. Effective Route Cache Maintenance: Affinity Based Timeout Mechanism

Each host in an ad-hoc network can maintain a route cache wherein the routes 'learnt' by this node from the past route discoveries are stored. Route cache reduces the route search latency as the intermediate host can reply to the source if its cache has a route to the destination. In addition, the data packets can be salvaged by directing them along an alternative route, in case the existing route fails.

The concept of affinity can be employed for an effective management of the route cache. After choosing an appropriate route, the destination sends a route reply to the source. As the route reply packet propagates to the source, an intermediate host receiving this packet stores the next hop information for a route to every possible node in the route request packet. With every such entry, a route cache timeout value equal to the minimum affinity along the route corresponding to the entry is associated. For instance, if the route cache entry at a node x_i for a destination node x_n is $(x_i x_{i+1} \ldots x_n)$, then

$$T = \min (a_{j, j+1})$$

where T is the route cache timeout for this route entry and aj, j+1 is the link affinity between node xj and xj+1.

A route entry is purged from the cache after the expiry of the route cache timer. The rationale behind this scheme is that the minimum affinity along a path is the value after which the weakest link along that path is expected to fail. An intermediate host can reply to a route request if it has an unexpired entry to the destination. Negative route information in the form of route error packets also assists the purging of stale routes. If a host has multiple routes to the same destination, the host replies to a route request with a route having the longest remaining route timeout value.

3. Affinity Based Dynamic Power Adjustment Scheme

Mobile hosts in an ad-hoc network have limited power at their disposal. A mobile node transmits packets at a fixed transmission power, irrespective of the location of the neighbouring nodes. The knowledge of link affinity equips us to dynamically adjust the power at which a host sends data packets to the successive nodes along a route. This helps conserve battery power at each node. For example, in a 200s TCP session, the number of packets transmitted by the source can reach a maximum of 25,000. With such a large number of packets being forwarded by the nodes along a route, the power consumption effected by dynamic variation of transmission power can be quite significant.

We assume that the links are bi-directional in nature. On receiving a *hello* message from a neighbour, a node infers the signal strength at which the neighbour receives packets from the node . Let the time between two successive hello packets be denoted by τ. S_{thresh} is the threshold signal strength and a is the link affinity between a node and its neighbour. When a hello packet arrives at the node with signal strength S_H at time t, the updated value of signal strength with which packets reach the neighbour in the interval $(t, t+\tau)$ is $S_{t, t+\tau.}$

When the residual link lifetime is less than the time between arrival of two consecutive hello packets, we do not adjust the power. When the node moves closer, the signal strength from a neighbour increases and is greater than S_H in the interval $(t, t+\tau)$. If the neighbour is moving away, we estimate the rate of change of signal strength and on that basis predict the signal strength till the arrival of the next hello packet. The signal strength at which the neighbour receives packets from a node is then given by the relation,

$$S_{t, t+\tau} = \begin{cases} S_H + \left(\dfrac{S_H - S_{thresh}}{a} \right) * \tau & \text{for recession } \& \ \tau < a \\ S_H & \text{for approach } \& \ \tau < a \\ S_{thresh} & \text{otherwise} \end{cases}$$

The power variation at a node that conforms to the signal strength variations at the neighbour of this node, is given by,

$$P_{t,t+\tau} = P_T * \frac{S_{thresh}}{S_{t,t+\tau}}$$

Where $P_{t,t+\tau}$ is the normal transmission power. For multiple connections, the adjusted power is the maximum of such individual values for each node. We have tested this scheme for a few simple scenarios. The power savings have been found to vary between 3-5%.

4. Conclusion

The assessment of link connectivity in a mobile ad-hoc network has numerous applications that help counter the mobility-induced mal-effects. We have discussed an optimal route selection based protocol wherein the affinity appraisal is utilized to estimate the residual-route-lifetime. The protocol has been shown to outperform the existing ad-hoc routing protocols for medium to large average speed of the nodes. Another useful application of affinity calculation that has been discussed herewith is the route cache management scheme. Finally the affinity based dynamic power adjustment scheme has been proposed.

5. Future Work

In the proposed RABR protocol, an intermediate hosts between the source and the destination broadcasts a given route request only for the first time. However, a better route from the source to the intermediate host might arrive after some delay. We have found that allowing an intermediate node to forward every request that comes to it causes a large routing overhead. We intend to explore this issue further.

We intend to assess the performance of the proposed protocol with the route cache management scheme suggested in Section 3. Although the destination no longer has the complete authority to choose the optimal route, the route establishment latency is reduced in this case.

Affinity is an estimate of the time after which a neighbour will move out of the threshold signal boundary of a mobile host, and hence is a measure of link availability. The affinity calculation that we have used in our implementation is not very accurate. A more robust calculation of the affinity can be made by calculating the distance between two nodes based on a series of signal strength measurements and employing an appropriate signal attenuation model.

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