Synthesizing Routing Protocols for Ad-hoc Mobile Networks *

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Abstract

We investigate the impact of different mobility rates on the performance of routing protocols in ad-hoc mobile networks. Based on our investigation, we design a new protocol that results from the synthesis of the well known protocols: ZRP and RUNNERS. We have implemented the new protocol as well as the original two protocols and conducted an extensive, comparative simulation study of their performance. The new protocol behaves well both in networks of diverse mobility motion rates, and in some cases even outperforms the original ones by achieving lower message delivery delays.

1. Introduction

In ad-hoc mobile networks, a node H_s that wants to communicate with H_r might not be within communication range but could communicate if other hosts lying "in between" them are willing to forward packets for them. In such networks, the natural motion of the mobile hosts causes frequent, unpredictable changes on the topological connectivity of the network which has a significant impact on the performance of routing protocols. The simplest way to establish communication in such nets is to perform flooding. Towards avoiding flooding several protocols have been proposed. One approach tries to construct and dynamically update paths between the mobile hosts. The second approach instead avoids path creation and maintenance by rather taking advantage of the hosts movement and accidental meetings in the network area.

The algorithms that follow *the path construction and maintenance approach* construct a connectivity related dynamic data structure (e.g. a dynamic graph) representing the topology of the network by a series of message passes. Using such a data structure, messages can be transmitted over a limited number of intermediate hosts that interconnect H_s with H_r, also known as *routing paths* or *routes*. In [6], TORA (Temporally-Ordered Routing Algorithm) is designed to minimize reaction to topological changes by localizing routing-related messages to a small set of nodes near the change. In [5, 7] an attempt is made to combine proactive and reactive approaches in the Zone Routing Protocol (ZRP) by initiating route discovery phase on-demand, but limit the scope of the proactive procedure only to the initiator's local neighborhood.

The protocols that follow *the "Support" approach* are designed for highly dynamic movement of the mobile users by taking advantage of the mobile hosts natural movement and exchanging information whenever mobile hosts meet incidentally ([4]). The approach proposes the idea of forcing a small subset of the deployed hosts to move as per the needs of the protocol, which is called the "support" of the network (denoted by Σ). As-

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suming the availability of such hosts, the designer can use them suitably *by specifying their motion* in certain times that the algorithm dictates. This approach may be useful in cases of rapid deployment of a number of mobile hosts, where it is possible to have a small team of fast moving and versatile vehicles to implement the support or even a collection of independently controlled mobile modules, e.g., robots.

In this work, we study the effect of the *mobility (or motion) rate* of the hosts, which is the parameter that dominates mostly the performance and the correctness of the protocols regardless of the approach followed. We carried out a detailed investigation that highlights the advantages and disadvantages of each approach and its suitability for a certain network and user *mobility (or motion) rate* using two representative protocols of the two approaches; namely, the ZRP protocol, and the RUNNERS protocol. Our simulation study suggests that the ZRP protocol that follow the path construction approach is more suitable for networks of low mobility rates since it manages to deliver the majority of the messages achieving relatively short delays. However, when the mobility rate of the hosts increases, the network experiences longer delays and lower delivery rates (i.e., messages are lost). On the other hand, the RUNNERS protocol that follows the support approach seems to be less affected by the mobility rate of the hosts, since it manages to deliver almost all the messages for all rates of motion. In fact, as the mobility rate of the hosts increases, the protocol benefits from their high mobility and reduces the average message delivery delays. However, although messages reach their destination, the message delivery delays are (on the average) higher than the corresponding delays of the ZRP protocol.

In view of the above, we are interested in designing a new routing protocol that achieves good results (in terms of message delivery rates and delays) in ad-hoc mobile networks consisting of mobile hosts with mixed mobility rates. Ideally, we would like to synthesize the two different approaches in a way such that the new routing protocol will benefit from the very high delivery rates of the support approach, while delivering the messages with short delays as done by the protocols that follow the path construction approach. For this reason we have propose a new protocol based on the *synthesis* of ZRP with the RUNNERS routing protocol.

Our experimental study shows that the new protocol operates well in networks of diverse mobility rates achieving high message delivery rates, while keeping the message delivery delays low. In fact, in some cases the resulting protocol synthesis outperform the original ones by achieving lower message delivery delays. We believe that our results on synthesizing different routing protocols are a step forward in creating a unifying framework for ad-hoc mobile networks comprised of mobile hosts with heterogeneous mobility rates.

2. The Zone Routing Protocol

The Zone Routing Protocol (ZRP) presented in [5, 7] is a hybrid proactive/reactive routing protocol, suitable especially for mobile ad-hoc networks with large network spans and diverse mobility rates. In ZRP each node proactively maintains routes to destinations within a local region, referred to as the routing zone, and the topological changes are only locally propagated. A node's *routing zone* is defined as a collection of nodes whose minimum distance (in hops) from the node in question is no greater than the zone radius protocol parameter. As a result, routing zones of nearby nodes may overlap heavily. When data needs to be sent to a destination-member of its routing zone, the necessary routing information is instantly available. Otherwise, a route query/reply mechanism is initiated in order to acquire a route to the destination. The knowledge of the routing zone topology improves the efficiency of the reactive route query/reply mechanism and assists in the maintenance of the discovered route after changes in network topology.

The ZRP actually consists of three different protocols, which exchange information and services in order to effect reliable and efficient communication between nodes of a mobile ad-hoc network. These protocols are: (i) the *Intrazone Routing Protocol* (IARP) that proactively maintains the routing zone topology of each node; (ii) the *Interzone Routing Protocol* (IERP) that reactively acquires routes to destinations beyond the routing zone using a route query/reply mechanism and also maintains the discovered routes after changes in network topology; and (iii) the *Bordercast Resolution Protocol* (BRP) that is a service used by the IERP for the efficient distribution, in the network, of its route query messages.

3. The Runners Support Routing Protocol

The Runners Support Routing Protocol is presented in [1, 2] and the main idea is as follows. First, we assume that there is a *setup phase* in the network, during which the support Σ of the network is formed. This can be done either by a randomized process, that randomly selects a number of mobile users or alternatively, the implementor may provide a specific number of mobile hosts (with specialized specifications, such as fast moving and versatile vehicles) that will form the support Σ. This small team of $k = |\Sigma|$ mobile hosts to move fast enough so that they cover (in sufficiently short time) the entire network area (the move of the rest is not affected by the protocol), by performing concurrent and independent random walks in the network area.

Each mobile host that wants to send some information to another host sends its message to any member σ of Σ whenever σ comes within its transmission range. The presence of a support member is advertised using an underlying subprotocol (see [4]). In addition, during this communication, it can receive any messages that have designated it as the receiver. When two runners meet, they exchange any information given to them by senders encountered using a *synchronization subprotocol*. In this way, a message delivered by some runner will be removed from the memory of the rest of runners encountered, and similarly delivery receipts already given will be discarded from the memory of the rest of runners. Hence, the support serves as a set of mobile *relay* hosts, that temporarily buffer messages (and delivery receipts) until they get delivered. Since Σ moves randomly around the area of the ad-hoc network, it will cover the entire area in sufficiently short time, thus servicing effectively all messages.

4. ZRP-Runners Protocols Synthesis

The protocol synthesis, which we call ZRP-R, is based on the synthesis of the ZRP and RUNNERS protocols. We take advantage of the modular nature of ZRP and replace the *Interzone routing protocol* (IERP) and the *Bordercast Resolution Protocol* (BRP) by the RUNNERS protocol. Each mobile host that wants to send some information to another host first consults the routing information of its local routing zone by using the *Intrazone Routing Protocol* (IARP). Thus, when data needs to be sent to a destination-member of its routing zone, the necessary routing information is instantly available. If no such routing information is available, the outgoing messages are forwarded directly to the RUNNERS protocol.

We here note that the synthesis proposed in this section can be appropriately modified to use other proactive protocols, i.e. other than ZRP. We are currently studying such kind of variations and plan to further investigate the idea of synthesizing a proactive routing protocol with the RUNNERS protocol.

5. Experimental Findings

We chose the lightweight adhocsim environment to be able to study very large instance sizes ([2, 4]). We however plan to also study the behavior of the protocols using a detailed network simulator (e.g. ns-2), that more accurately takes into account the network parameters.

We carried out each experiment for a very large number of rounds (at least $10,000$) during which a very large number of messages (at least $200,000$) were delivered to the designated receivers. We deployed 50 mobile hosts with message generation rate λ to 0.02 (e.g. a new message is generated every 200 rounds). The destination of each new message is selected randomly and there is no limit on the total number of sender-receiver pairs. The motion of the mobile hosts is modelled by concurrent and independent random walks with *mobility (or motion) rate* $\mu \in [0, 1]$, i.e. the probability with which the mobile host will move in a round of the protocol. Finally, we considered 2D grid motion graphs of size $n = 121$ to model different geographic areas. For more information regarding the modelling assumptions, see [2–4].

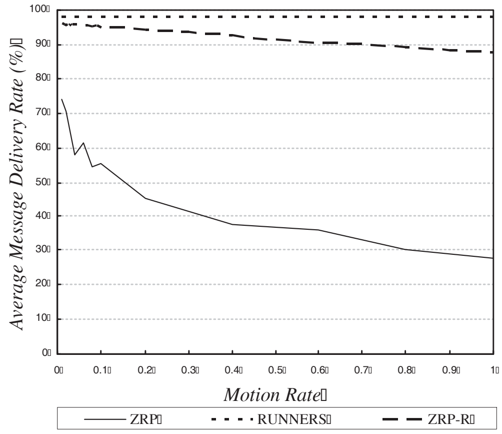

Figure 1: Average Msg Delivery Rate ($\mathcal{D}$)

In the ZRP implementation the *routing zone radius* was set to 3, based on the experiments presented in [7], and the number of the *route request retries* was set to 2. For the RUNNERS protocol we set the support size k to 10. The proper selection of k is studied thoroughly in [2]. Note that the mobile hosts that belong to the support move continuously ($\mu = 1$).

For the average delivery rate (see Fig. 1), we observe that the motion rate of the users has a great impact on the performance of ZRP, while it seems to have no effect on the RUNNERS protocols. In fact, ZRP delivers more than 50% of the messages for low rates of motion (e.g., $\mu \leq 0.2$), while for higher rates (e.g., $\mu \geq 0.6$) the delivery rate drops below 35%. The RUNNERS protocol exhibits a completely different behavior: it achieves a very high delivery rate for all “frequencies” of motion. Regarding the new protocol, we observe that the average message delivery rate ($\mathcal{D}$) of ZRP-R is very close to

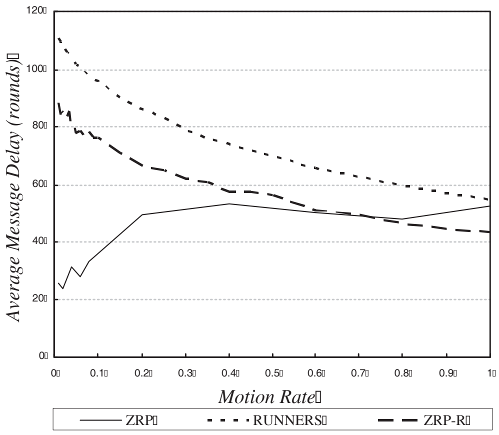

Figure 2: Average Message Delay ($\mathcal{T}$)

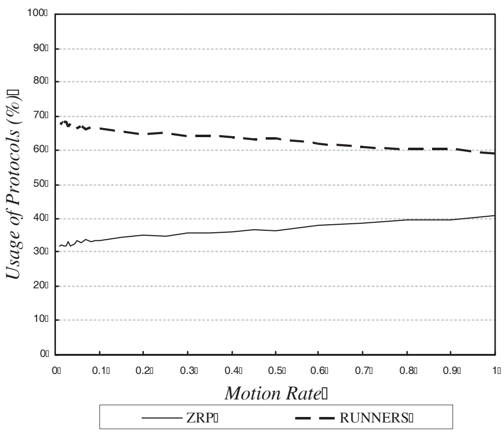

Figure 3: Average usage of each protocol in ZRP-R based on delivered messages

that of RUNNERS.

Figure 2 depicts the effect of the motion rate on the average message delay. We observe that the performance of the ZRP protocol degrades as the rate of motion increases, i.e., the average message delay increases as the users of network move more frequently. Again, the RUNNERS protocol has a completely different behavior; that is, the average message delay drops as the rate of motion of the hosts increases. This can be explained by the fact that as the users are moving more frequently, they will meet the nodes of the support more often. In this way, the messages will be delivered to the support and to their final destination faster. Thus, the RUNNERS protocol is particularly suitable in the case of high mobility rate, since increasing motion seems to positively affect its performance by accelerating meeting times. Finally, for the new protocol, we observe that ZRP-R outperforms ZRP in cases of high mobility rates ($\mu \geq 0.65$) and it outperforms RUNNERS for all values of μ.

Interestingly, the synthesized protocols ZRP and RUNNERS are used interchangeably for all values of the motion rates considered, as it is shown in Fig. 3. We believe that the modular nature of ZRP allows such high cohesion, resulting in this way to a protocol synthesis that, in some cases, outperforms both original ones.

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