Utility Based Routing in Mobile Networks

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Abstract— Self Adaptive Utility based Routing SAURP is characterized by the ability of identifying potential opportunities of forwarding messages to their destinations through a novel utility function based mechanism in which a suite of environment parameters, such as wireless channel condition, nodal buffer occupancy, and encounter statistics, are jointly considered. SAURP can resend messages among nodes providing high buffer occupancy, wireless interference and congestion by providing small number of transmissions. The developed utility function in SAURP is proved to be able to achieve optimal performance, which is further analysed via a stochastic modelling approach. Extensive simulations are conducted to verify the developed analytical model and compare the proposed SAURP with a number of recently reported encounter-based routing approaches in terms of delivery ratio, delivery delay, and the number of transmissions required for each message delivery. The simulation results show that SAURP outperforms all the counterpart multi-copy encounter-based routing protocols considered in the study. In this we introduce a novel multi-copy routing protocol, called Self Adaptive Utility-based Routing Protocol (SAURP), for Delay Tolerant Networks (DTNs) that are possibly composed of a vast number of devices in miniature such as smart phones of heterogeneous capacities in terms of energy resources and buffer spaces.

Keywords— Encounter-based Routing, DTN.

I. INTRODUCTION

Delay Tolerant Network (DTN) is characterized by the lack of end-to-end paths for a given node pair for extended periods, which poses a completely different design scenario from that for conventional mobile ad-hoc networks (MANETs). Due to the intermittent connections in DTNs, a node is allowed to buffer a message and wait until the next hop node is found to continue storing and carrying the message. Such a process is repeated until the message reaches its destination. This model of routing is significantly different from that employed in the MANETs. DTN routing is usually referred to as encounter-based, store-carry-forward, or mobility-assisted routing, due to the fact that nodal mobility serves as a significant factor for the forwarding decision of each message.

Depending on the number of copies of a message that may coexist in the network, two major categories of encounter-based routing schemes are defined: single-copy and multi-copy. With the single-copy schemes, no more than a single copy of a message can be carried by any node at any instance. Although simple and resource efficient, the main challenge in the implementation of single-copy schemes lies in how to effectively deal with the interruptions of network connectivity and node failures. Thus, single-copy schemes have been

reported to seriously suffer from long delivery delays and/or large message loss ratio. On the other hand, multiple-copy (or multi-copy) routing schemes allow the networks to have multiple copies of the same message that can be routed independently and in parallel so as to increase robustness and performance. It is worth noting that most multi-copy routing protocols are flooding-based that distribute unlimited numbers of copies throughout the network, or controlled flooding-based that distribute just a subset of message copies, or utility-based approaches that determine whether a message should be copied to a contacted node simply based on a developed utility function.

Although improved in terms of performance, the previously reported multi-copy schemes are subject to the following problems and implementation difficulties. First, these schemes inevitably take a large number of transmissions, energy consumption, and a vast amount of transmission bandwidth and nodal memory space, which could easily exhaust the network resource. Second, they suffer from contention in case of high traffic loads, when packet drops could result in a significant degradation of performance and scalability. Note that the future DTNs are expected to operate in an environment with a large number of miniature hand-held devices such as smart phones, tablet computers, personal digital assistants (PDAs), and mobile sensors. In such a scenario, it may no longer be the case that nodal contact frequency serves as the only dominant factor for the message delivery performance as that assumed by most existing DTN literature. Therefore, limitations on power consumption, buffer spaces, and user preferences should be jointly considered in the message forwarding process.

To cope with the above-mentioned deficiency, a family of multi-copy schemes called utility-based controlled flooding has been proposed. The class of schemes generate only a small number of copies to ensure that the network is not overloaded with the launched messages. Although being able to effectively reduce the message delivery delay and the number of transmissions, most of the utility-based controlled flooding routing schemes in literature assume that each node has sufficient resources for message buffering and forwarding. None of them, to our best knowledge, has sufficiently investigated how the protocol should take advantage of dynamic network status to improve the performance, such as packet collision statistics, wireless link conditions, nodal buffer

occupancy, and battery status. Note that the nodal buffer status could serve as an indicator how much the opportunity cost is by accepting a forwarded message; while the channel condition is an indicator how likely the contact could be an eligible one; or in other words, how likely a message can be successfully forwarded during the contact. They are obviously essential parameters to be considered in the utility function.

With this in mind, we introduce a novel DTN routing protocol, called Self Adaptive Utility-based Routing Protocol (SAURP), which aims to overcome the shortcomings of the previously reported multi-copy schemes. Our goal is to achieve a superb applicability to the DTN scenario with densely distributed hand-held devices. The main feature of SAURP is the strong capability in adaptation to the fluctuation of network status, traffic patterns/characteristics, user encounter behaviours, and user resource availability, so as to improve network performance in terms of message delivery ratio, message delivery delay, and number of transmissions.

The contributions of the paper are as following We develop a novel DTN routing scheme which incorporates with some parameters that have not been jointly considered in the literature. The parameters include link quality/availability and buffer occupancy statistics, which are obtained by sampling the channels and buffer space during each contact with another node.

We introduce a novel transitivity update rule, which can perfectly match with the proposed routing model and the required design premises.

We introduce a novel adaptive time-window update strategy for maintaining the quality metric function at each node, aiming at an efficient and optimal decision making process for each active data message.

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II. SELF ADAPTIVE UTILITY-BASED ROUTING PROTOCOL(SAURP)

The proposed SAURP is characterized by the ability of adapting itself to the observed network behaviours, which is made possible by employing an efficient time-window based update mechanism for some network status parameters at each node.

We use time-window based update strategy because it is simple in implementation and robust against parameter fluctuation. Note that the network conditions could change very fast and make a completely event-driven model unstable. Fig. 1 illustrates the functional modules of the SAURP architecture along with their relations.

The Contact Statistics (denoted as $CS^{(i)}$) refers to the statistics of total nodal contact durations, channel condition, and buffer occupancy state. These values are collected at the end of each time window and used as one of the two inputs to the Utility-function Calculation and Update Module (UCUM). Another input to the UCUM, as shown in Fig. 1, is the updated utility denoted by $4T_{new}^{(i)}$, which is obtained by feeding $4T^{(i)}$ (the inter-contact time between any node pair, A and B) through the Transitivity Update Module (TUM). UCUM is applied such that an adaptive and smooth transfer between two consecutive time windows (from cur-rent time-window to next time-window) is maintained. $4T^{(i+1)}$ is the output of UCUM, and is calculated at the end of current time window $W^{(i)}$. $4T^{(i+1)}$ is thus used in time window $W^{(i+1)}$ for the same tasks as in window $W^{(i)}$.

Forwarding Strategy Module (FSM) is applied at the custodian node as a forwarding decision making process when encountering any other node within the current time window based on the utility value (i.e., $4T^{(i)}$).

It is important to note that CS, TUM, FSM, and message vector exchange are event-driven and performed during each contact, while UCUM is performed at the end of each time-window. The following subsections introduce each functional module in detail.

A. Contact Statistics (CS)

To compromise between the network state adaptability and computation complexity, each node continuously updates the network status over a fixed time window. The maintained network states are referred to as Contact Statistics (CS), which include nodal contact durations, channel conditions, and buffer occupancy state, and are fed into UCUM at the end of each time window. The CS collection process is described as follows.

Let two nodes A and B be in the transmission range of each other, and each broadcasts a pilot signal per k time units in order to look for its neighbours within its transmission range. Let $T_{(A,B)}$, T_{free}, and T_{busy} represent the total contact time, the amount of time the channel is free and the buffer is not full, and the amount of time the channel is busy or the buffer is full, respectively, at node A or B during time window $W^{(i)}$. Thus, the total duration of time in which node A and B can exchange information is calculated as:

$$T_{free} = T_{(A,B)} - T_{busy} \qquad (1)$$

B. Utility-function Calculation and Update Module (UCUM)

UCUM is applied at the end of each time window and is used to calculate the currently observed utility that will be further used in the next time window. The two inputs to UCUM in time window $W^{(i)}$ are: (i) the predicted inter-contact time ($\Delta T^{(i)}$), which is calculated according to the previous time-window utility (i.e., $\Delta T^{(i)}$), as well as an update process via the transitivity property update (introduced in subsection 2.3), and (ii) the observed inter-encounter time obtained from the current $CS^{(i)}$ (denoted as $\Delta T_{cs}^{(i)}$).

C. The Transitivity Update Module (TUM)

When two nodes are within transmission range of each other, they exchange utility vectors with respect to the message destination, based on which the custodian node decides whether or not each message should be forwarded to the encountered node. With a newly received utility vector, transitivity update [2] is initiated. We propose a novel adaptive transitivity update rule, which is different from the previously reported transitivity up-date rules [2]. [6]. The proposed transitivity update rule is characterized as follows: (1) it is adaptively modified according to a weighting factor , which is in turn based on the ratio of $4T^{(i)}$ of the two encountered nodes regarding the destination rather than using a scaling constant. Note that the weighting factor determines how large impact the transitivity should have on the utility function. (2) It can quantify the uncertainty regarding the position of the destination by only considering the nodes that can effectively enhance the accuracy of the utility function.

The transitivity property is based on the observation that if node A frequently encounters node B and B frequently encounters node D, then A has a good chance to forward messages to D through B. Such a relation is implemented in the proposed SAURP using the following update strategy:

D. The Forwarding Strategy Module (FSM)

The decision of message forwarding in SAURP is mainly based on the utility function value of the encountered node regarding the destination, and the number of message copy tokens. If more than one message copy is currently carried, the weighted copy rule is applied; otherwise the forwarding rule is applied.

1. Weighted Copy Rule: The source of a message initially starts with L copies. In the event that any node A that has n > 1 message copy tokens and encounters another node B with no copies $\Delta T^{(i)}_{(B,D)} < \Delta T^{(i)}_{(A,D)}$[1] node A hands over some of the message copy tokens to node B and keeps the rest for itself.

2. The Forwarding Rule:

- If the destination node is one hop away from an encountered node, the custodian node hands over the message to the encountered node and completes the message delivery.
- If the inter-encounter time value of the encountered node relative to that of the destination node is less than that of the custodian node by a threshold value, $4T_{th}$, a custodian node hands over the message to the encountered node.

The complete mechanism of the forwarding strategy in SAURP is summarized as shown in Algorithm 1.

Algorithm 1 The forwarding strategy of SAURP
On contact between node A
and B Exchange summary
vectors
for every message M at buffer of custodian node A
  do if destination node D in transmission range
  of **B then**
    A forwards message copy to B
  end if
  else if $\Delta T^{(i)}_{(A,D)} > \Delta T^{(i)}_{(A,D)}$ **do**
    if message tokens >1 **then**
      apply weighted copy rule
    end if
    else if $\Delta T^{(i)}_{(A,D)} > \Delta T^{(i)}_{(A,D)} + \Delta T_{th}$ **then**
      A forwards message
     to B **end else if**
 e
nd
else if
end
for

III. ANALYTICAL MODEL OF SAURP

In this section a statistical analysis is conducted to evaluate the performance of SAURP. Without loss of generality, Community-Based Mobility Model [6] is employed in the analysis. The problem setup consists of an ad hoc net-work with a number of nodes moving independently on a 2-dimensional torus in a geographical region, and each node belongs to a predetermined community.
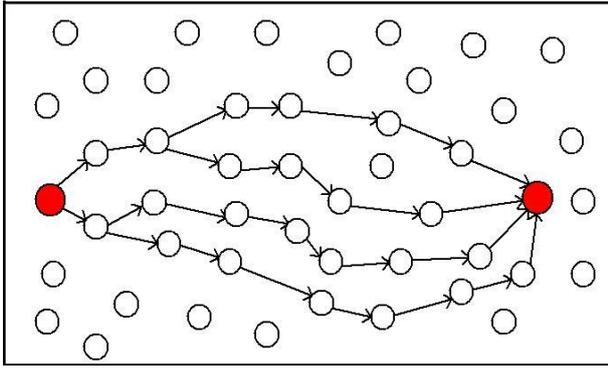
Fig. 1. Paths of message copies to destination

Each node can transmit up to a distance K 0 meters away, and each message forwarding (in one-hop) takes one time unit. Euclidean distance is used to measure the proximity between two nodes (or their positions) A and B. A slotted collision avoidance MAC protocol with Clear-to-Send (CTS) and Request-to-Send (RTS), is implemented for contention resolution. A message is acknowledged if it is received successfully at the encountered node by sending back a small acknowledgment packet to the sender.

The performance measures in the analysis include the average delivery probability and the message delivery delay. The analysis is based on the following assumptions.

- Nodes mobility is independent and heterogeneous, where nodes have frequent appearance in some locations.
- Each node in the network maintains at least one for-warding path to every other node. Fig. 1 illustrates the paths that a message copy may take to reach the destination.
- Each node belongs to a single community at a time (representing some hot spots such as classrooms, office buildings, coffee shops), and the residing time on a community is proportional to its physical size.

A. Delivery Probability

In order to calculate the expected message delivery ratio, any path of message m between *S* and *D* is a *k - hop* simple path, denoted a *l*, which is represented by a set of nodes and links denoted as *{S, h_1 h_2....h_{k-1}, D}*, and *{e_1, e,...., e_k}*, respectively. The cost on each edge, denoted as *{$\beta_1 < \beta_2 < .. < \beta_k$}*, is the inter-contact rate (or frequency) of each adjacent node pair along the path. According to the forwarding policy of SAURP, the values of inter-contact rate should satisfy *{$\beta_1 < \beta_2 < .. < \beta_k$}*. The path cost, $PR_l(t)$, is the probability that a message m is successfully forwarded from S to D along path l within time t, which represents a cumulative distribution function (CDF). The probability density function of a path l with k hop for one message

copy can be calculated as convolution of k probability distributions [27] which is calculated as:

$$Pr_l(t) = p_1(t) * p_2(t) * .... p_k(t) \qquad (1)$$

B. Validation of Analytical Model

In order to evaluate the accuracy of the mathematical expressions in this analysis, SAURP is examined under two network status scenarios. In the first scenario, the network is operating under no congestion, i.e., all the nodes have infinite buffer space, and the bandwidth is much larger than the amount of data to be exchanged between any two encountered nodes. In the second scenario, the network is operating under limited re-sources, i.e., the forwarding opportunities can be lost due to high traffic, limited bandwidth, limited buffer space or contention (i.e., more than one node within the transmission range are trying to access the wireless channel at the same time). For both scenarios, 50 nodes move according to community-based mobility model [6] in a 300x300 network area. The transmission range is set to 30 to enable moderate network connectivity with respect to the considered network size. The traffic load is varied from a low traffic load (i.e., 20 messages generated per node in 40,000 time units) to high traffic load (i.e., 80 messages generated per node in 40,000 time units). A source node randomly chosen a destination and generates messages to it during the simulation time. In this analysis the message copies are set to 5 (i.e., forming a maximum of 5 paths).

Examining SAURP under the two scenarios is very important; in case of no congestion, the best path that is taken by a message is mainly based on the inter-encounter time, while under congestion, the message will be buffered for longer period of time and enforced to take longer path to go around the congested area resulting in more dropping rate and longer delivery delay.

To enable accurate analysis, the simulation program is run for a period of time (warm up period of 10,000 time units) such that each node can build and maintain the best forwarding paths with every other node in the network. These forwarding paths are mainly based on the congestion degree (traffic loads values) considered in the analysis. The forwarding path is cached by following the trajectories of the generated messages during the warm up stage between every source destination pair in the network. These messages are forwarded from node to node according to SAURP routing mechanism.

In this analysis, we simplified the calculation by limiting our study to only the best two of forwarding paths among all other paths and compare the simulation and theoretical results of

delivery ratio and delivery delay. In most cases, a message takes the best forwarding path that based on the inter-encounters history if the network is not congested and the buffers operate under their capacity limit.

IV. PERFORMANCE EVALUATION

1. Experimental Setup

To evaluate the SAURP, a DTN simulator similar to that in is implemented. The simulations are based on two mobility scenarios; a synthetic one based on community based mobility model (CBMM) and a real world encounter traces collected as part of the Infocome 2006 experiment.

The problem setup consists of an ad hoc network with a number of nodes moving independently in a geographical region, and each node belongs to a predetermined community. Each node can transmit up to a distance K 0 meters away, and each message transmission takes one time unit. A slotted collision avoidance MAC protocol with Clear-to-Send (CTS) and Request-to-Send (RTS) is implemented for contention resolution. A message is acknowledged if it is received successfully at the encountered node by sending back a small acknowledgment packet to the sender. The performance of SAURP is examined under different network scenarios and is compared with some previously reported schemes listed below.

B. CBMM Scenario

1. Evaluation Scenarios: In the simulation, 110 nodes move according to the community-based mobility model [6] in a 600 x 600 meter network in a given geographical region. The simulation duration is 40,000 time. The message inter-arrival time is uniformly distributed in such a way that the traffic can be varied from low (10 messages per node in 40,000 time units) to high (70 messages per node in 40,000 time units). The message time to live (TTL) is set to 9,000 time units. Each source node selects a random destination node, begins generating messages to it during simulation time.

We analyse the performance implication of the following. First, the performance of the protocols is evaluated with respect to the impact of the number of message copies. Second, with respect to the low transmission range and varying buffer capacity under high traffic load. Third, with respect to the moderate-level of connectivity and varying traffic load. Fourth, the performance of the protocols is examined in terms of the bandwidth. Finally, the performance of the protocols is examined in terms of the level of connectivity changes.

V. CONCLUSION

The paper introduced a novel multi-copy routing scheme, called SAURP, for intermittently connected mo-bile networks that are possibly formed by densely distributed and hand-held devices such as smart phones and personal digital assistants. SAURP aims to explore the possibility of taking mobile nodes as message carriers in order for end-to-end delivery of the messages. The best carrier for a message is determined by the prediction result using a novel contact model, where the network status, including wireless link condition and nodal buffer availability, are jointly considered. We provided an analytical model for SAURP, whose correctness was further verified via simulation. We further compared SAURP with a number of counterparts via extensive simulations. It was shown that SAURP can achieve shorter delivery delays than all the existing spraying and flooding based schemes when the network experiences considerable contention on wireless links and/or buffer space.

The study provides significance that when nodal contact does not solely serve as the major performance factor, the DTN routing performance can be significantly improved by further considering other resource limitations in the utility function and message weighting/forwarding progress. easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

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