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An Adaptive Utility-Based System Routing Protocol

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Abstract

Self Adaptive Utility-based Routing Protocol (SAURP) is a new multi-copy routing protocol for Delay Tolerant Networks (DTNs) that could be made up of a large number of small devices, like smartphones, with different energy resources and buffer spaces. SAURP can detect possible chances to send messages to their destinations by using a new mechanism based on utility functions. This mechanism takes into account a number of environmental factors, including the state of the wireless channel, the occupancy of nodal buffers, and encounter statistics. This means that SAURP may redirect messages around nodes that are suffering congestion, high buffer occupancy, or wireless interference with very few transmissions. Optimal performance can be achieved by the SAURP utility function that was constructed; this is further investigated using a stochastic modeling technique. The proposed SAURP is compared to many previously published encounter-based routing methods in terms of delivery ratio, delivery latency, and the number of transmissions necessary for each message delivery. Extensive simulations are run to validate the constructed analytical model. According to the findings of the simulations, SAURP is the best of the multi-copy encounter-based routing protocols that were investigated for the study.

Keywords

Dutta, Saur

I. Introduction

Delay Tolerant Network (DTN) [1] 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 adhoc networks (MANETs) [13]. As a workaround for DTNs' sporadic connections, a node can temporarily store a message in its buffer before continuing to transmit it to the next hop node. Until the message reaches its intended recipient, this procedure is repeated. The routing paradigm used in MANETs is very different from this one. 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.

Although improved in terms of performance, the previously reported multi-copy schemes are subject to the following problems and implementation difficulties.

To begin with, the network resource might be quickly depleted due to the high energy consumption, many transmissions, and enormous amounts of transmission bandwidth and node memory space required by these systems. Second, they suffer from contention in case of high traffic loads, when packet drops could result in a significant degradation of performance and scalability. Keep in mind that futuristic DTNs will presumably function in a setting with a plethora of small, handheld devices, including smartphones, tablets, PDAs, and mobile sensors. Assumed by the majority of the current DTN research, nodal contact frequency may no longer be the only determinant of message delivery success in such a situation. The message forwarding procedure should thus take power consumption limits, buffer space constraints, and user preferences into account simultaneously.

we introduce a novel DTN routing protocol, called Self Adaptive Utility-based Routing Protocol (SAURP), that aims to overcome the shortcomings of the previously reported multi-copy schemes. Our objective is to accomplish a highly applicable scenario with widely dispersed handheld devices in the DTN. Message delivery ratio, message delivery delay, and number of transmissions are all metrics for measuring network performance, and SAURP's primary strength is its adaptability to changing network status, traffic patterns/characteristics, user encounter behaviors, and user resource availability.

II. Literature Survey

Most (if not all) previously reported encounter-based routing schemes have focused on nodal mobility, which has been extensively exploited as the dominant factor in the message forwarding decision. Those schemes contributed in the context of introducing new interpretations of the observed node mobility in the per-node utility function.

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Nelson proposed an enhanced version of MSF by taking the number of message replicas transferred during each contact in proportion to the pernode utility function, which is in turn determined by the evolution of the number of nodal encounters during each time-window.

Lindgren et al. in Jones et al. in [11] introduced a novel utility function for DTN routing by manipulating the minimum expected inter-encounter duration between nodes. Ling et al. in designed a feedback adaptive routing scheme based on the influence factors solely determined by the node mobility, where a node with higher mobility is given a higher factor and messages are transmitted through nodes with higher influence factors.

Lindgren et al. in [2] introduced a DTN routing scheme which predicts encounter probability between nodes. Burgess et al. in introduced a routing protocol which bases its decisions on whether to transmit or delete a message on the path likelihood. The path likelihood metric is based on historic information of the number of encounters between nodes. Y. Liao et al. in introduced a routing scheme that combines erasurecoding with an estimation routing scheme and selectively distributes messages blocks to relay nodes. The decision of forwarding a message depends on the contact frequency and other factors such as buffer occupancy, and available battery power level.

To allocate resources, Balasubramanian et al. presented a routing mechanism in. The statistics of available bandwidth and the number of message replicas currently in the network are considered.

It derivation of the routing metric to decide which message to replicate first among all the buffered messages in the custodian node. The derivation of the routing metric, nonetheless, is not related to buffer status. Khrifa et al. in [14] proposed a forwarding and dropping policy for a limited buffer capacity. The decision under this policy is made based on the value of per-message marginal utility. This policy nonetheless was designed to suit homogeneous nodal mobility.

Lee et al. introduced a comprehensive routing scheme as resource allocation that jointly optimizes link scheduling, routing, and replication. This framework allows the developed solutions to be adaptive to various network conditions regarding nodal interferences and connections/disconnections. Tan et al. introduced a routing strategy based on calculating the expected end-to-end path length as a metric in forwarding messages mainly based on the reciprocal of the encountering probability. It is defined as the expectation of message transmission latency through multi-hop relays.

Another scheme is called delegation forwarding , where a custodian node forwards a message copy to an encountered node if the encountered node has a better chance to "see" the destination. The key idea is that a custodian node (source or relay) forwards a message copy only if the utility function (represented by the rate of encounters between node pairs) of the encountered node is higher than all the nodes so far "seen" by a message, and then current custodian will update its utility value of that message to be equal to that of the encountered node.

Mosli et al. in [13] introduced a DTN routing scheme using utility functions that are calculated from an evaluation of context information. The derived cost function is used as an assigned weight for each node that quantifies its suitability to deliver messages to an encountered node regarding to a given destination.

Spyropoulos et al. in [6], [12] developed routing strategies that use different utility routing metrics based on nodal mobility statistics, namely Most Mobile First (MMF), Most Social First (MSF) and Last Seen First (LSF). A sophisticated scheme was introduced by Spyropoulos et al., called Spay and Focus [6], which is characterized by addressing an upper bound on the number of message copies (denoted as L). In specific, a message source starts with L copy tokens. When it encounters another node B currently without any copy of the message, it shares the message delivery responsibility with B by transferring L/2 of its current tokens to B while keeping the other half for itself. When it has only one copy left, it switches to a utility forwarding mechanism based on the LSF (time elapsed since the last contact). This scheme has proven to significantly reduce the required number of transmissions, while achieving a competitive delay with respect to network contentions such as buffers space and bandwidth.

III. System Development

A. Self Adaptive Utility-Based Routing Protocol (SAURP)

The proposed SAURP is characterized by the ability of adapting itself to the observed network behaviors, which is made possible by employing an efficient timewindow 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 ΔT(i) new, which is obtained by feeding ΔT(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 current time-window to next time-window) is maintained. ΔT(i+1) is the output of UCUM and is calculated at the end of current time window W(i). ΔT(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., ΔT(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.

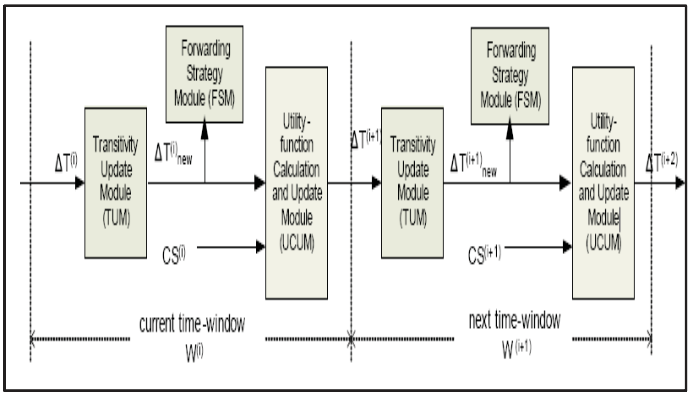

Fig. 1: The SAURP Architecture

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 neighbors within its transmission range. Let T(A;B), Tfree, and Tbusy 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:

Tfree = T(A;B) – Tbusy

Note that the total contact time could be accumulated over multiple contacts between A and B during W(i).

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 (ΔT(i)), which is calculated according to the previous time-window utility (i.e.,

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ΔT(i)), as well as an update process via the transitivity property update and (ii) the observed interencounter time obtained from the current CS(i) (denoted as ΔT(i) cs) [5-6].

1. Calculation of Inter-encounter Time (ΔT(i))

An eligible contact of two nodes occurs if the duration of the contact can support a complete transfer of at least a single message between the two nodes. Thus, in the event that node A encounters B for a total time duration Tfree during time window W(i), the number of eligible contacts in the time window is determined by:

$$n_c^{(i)} = \left\lfloor \frac{T_{free}}{T_p} \right\rfloor$$

where Tp is the least time duration required to transmit a single message. Let ΔT(i)cs(A;B) denotes the average inter-encounter time duration of node A and B in time W(i). Obviously, ΔT(i) (A;B) = ΔT(i)(B;A). We have the following expression for ΔT(i) cs(A;B):

$$\triangle T_{cs(A,B)}^{(i)} = \frac{W^{(i)}}{n_c^{(i)}}$$

ΔT(i)cs(A;B) describes how often the two nodes encounter each other per unit of time (or, the encounter frequency) during time window W(i) considering the event the channel is busy or the buffer is full. Thus, inter-encounter time of a node pair intrinsically relies rather on the duration and frequency of previous contacts of the two nodes than simply on the number of previous contacts or contact duration. Including the total duration of all the contacts (excluding the case when the channel is busy or the buffer is full) as the parameter is expected to better reflect the likelihood that nodes will meet with each other for effective message exchange.

2. Time-window Transfer Update

Another important function provided in UCUM is for the smooth transfer of the parameters between consecutive time windows. As discussed earlier, the connectivity between any two nodes is measured according to the amount of inter-encounter time during W(i), which is mainly based on the number of contacts (i.e., nc) and the contact time (i.e., Tfree). These contacts and contact durations may change dramatically from one time window to the other and address significant impacts on the protocol message forwarding decision. Hence, our scheme determines the next time window parameter using two parts: one is the current time window observed statistics(i.e., ΔT(i) cs), and the other is from the previous time window parameters (i.e., 4T(i)), in order to achieve a smooth transfer of parameter evolution. The following equation shows the derivation of 4T(i+1) in our scheme.

$$\triangle T^{(i+1)} = \gamma.\triangle T_{cs}^{(i)} + (1-\gamma)\triangle T^{(i)}$$

The parameter is given by

$$\gamma = \frac{|\triangle T^{(i)} - \triangle T_{cs}^{(i)}|}{max(\triangle T^{(i)}, \triangle T_{cs}^{(i)})}, \; where \; \triangle T^{(i)}, \; \triangle T_{cs}^{(i)} > 0$$

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If ΔT(i) cs > W, which happens if if n(i)c = 0, then
ΔT(i+1) = 2W/n(i□1)c.
This case represents a worst case scenario, i.e. unstable node behavior, or low quality of node mobility. Hence, the ΔT(i+1) value should be low. ΔT(i+1) represents the routing metric (utility) value that is used as input to the next time window. This value is maintained as a vector of inter-encounter time that is specific to every other node, which is employed in the decision making process for message forwarding.

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 update rules [2, 6]. The proposed transitivity update rule is characterized as follows: (1) it is adaptively modified according to a weighting factor α, which is in turn based on the ratio of ΔT(i) of the two encountered nodes regarding the destination rather than using a scaling constant. Note that the weighting factor α 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 Ahas a good chance to forward messages to D through B. Such a relation is implemented in the proposed SAURP using the following update strategy:

$$\Delta T^{(i)}_{(A,D)new} = \alpha \Delta T^{(i)}_{(A,D)} + (1-\alpha)(\Delta T^{(i)}_{(A,B)} + \Delta T^{(i)}_{(B,D)})$$

where α is a weighting factor that must be less than 1 to be valid:

$$\alpha = \frac{\Delta T^{(i)}_{(A,B)} + \Delta T^{(i)}_{(B,D)}}{\Delta T^{(i)}_{(A,D)}}, \ \Delta T^{(i)}_{(A,D)} > \Delta T^{(i)}_{(A,B)} + \Delta T^{(i)}_{(B,D)}$$

α has a significant impact on the routing decision rule. From a theoretical perspective, when a node is encountered that has more information for a destination, this transitivity effect should successfully capture the amount of uncertainty to be resolved regarding the position of the destination. To ensure that the transitivity effect can be successfully captured in the transitivity update process, an update should be initiated at node Aregarding D only when ΔT(i)(A;D) > ΔT(i)(B;D). Otherwise, the transitivity property for node A is not useful since node A itself is a better candidate for carrying the messages destined to node D rather than forwarding them through B. This rule is applied after nodes finish exchange messages.

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 are 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 with ΔT(i) (B;D) < 4T(i)(A;D), node A hands over some of the message copy tokens to node B and

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$$N_B = \left\lfloor N_A \left(\frac{\Delta T^{(i)}_{(A,D)}}{\Delta T^{(i)}_{(B,D)} + \Delta T^{(i)}_{(A,D)})} \right) \right\rfloor$$

where NA is the number of message tokens that node A has, ΔT(i) (B;D) is the inter-encounter time between node B and node D, and ΔT(i)(A;D) is the inter-encounter time between nodes A and D. This formula guarantees that the largest number of message copies is spread to relay nodes that have better information about the destination node. After L message copies have been disseminated to and carried by the encountered custodian nodes, each custodian node carrying the message performs message forwarding according to the forwarding rule as described in the next subsection. It may be noted here that the idea of weighted copy rule was firstly examined and has been proved to achieve improved delivery delay

[8].

2. The Forwarding Rule

- If the destination node is one hop away from an enco

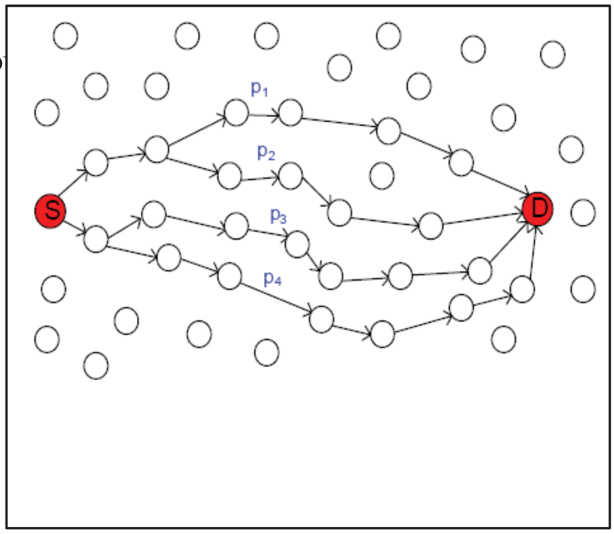

Fig. 2: Paths of Message Copies to Destination

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

-

Tick(ms)	Source	Destination node	Time at dest (in ms)
1	1	2	2
1	2	3	2
2	2	3	3
2	1	3	4
3	1	2	4

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Nodes mobility is independent and heterogeneous, where nodes have frequent appearance in some locations. Each node in the network maintains at least one forwarding path to every other node. Fig. 2 illustrates the paths that a message copy may take to reach the destination.
Eachnodebelongstoasinglecommunityatatime(representing some hot spots such as classrooms, office buildings, coffee shops), and the residing time on a community is proportional to its physical size.
The inter-contact time ΔT(A;B) between nodesAand B follows an exponential distribution with probability distribution function (PDF), P ΔT(A;B) (t) = β(A;B):e− β (A;B)t, where t is the time instance.
It has been shown that a number of popular user mobility models have such exponential tails (e.g., Random Walk, Random Waypoint, Random Direction, and Community-based Mobility [9]). In practice, recent studies based on traces collected from real-life mobility examples argued that the inter-contact time and the contact durations of these traces demonstrate exponential tails after a specific cutoff point. Based on the mobility model of the nodes, the distribution of the intercontact time can be predicted and calculated using time window updates. Thus, parameter β AB is calculated as β AB = 1/ΔT(A;B).

E. 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 network with a number of nodes moving independently on a 2-dimensional torus 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 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 [5].Performance Analysis
We analyze 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.

Conclusion

The report introduced a novel multi-copy routing scheme, called SAURP, for intermittently connected mobile 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 The study provides a 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 process.

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