Delay Tolerant Networks for Intermittently Connected Mobile Networks

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Abstract: *Self Adaptive Utility based Routing protocol SAURP is characterized by the ability of identifying probable opportunities of forwarding messages to their destination through a novel utility task based mechanism in which a suite of environment parameters, such as wireless channel situation, nodal buffer possession, and encounter information, are jointly considered. SAURP can resend messages among nodes on condition that 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 finest performance, which is further analyzed via a stochastic approach. Extensive simulation are conducted to verify the developed logical model and compare the proposed SAURP with a number of recently reported stumble upon-base routing approaches in terms of delivery proportion deliverance disruption, and the number of transmissions required for each message delivery. The simulation results show that SAURP Performance all the counterpart multi-copy stumble upon-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 huge number of devices in miniature such as smart phones of various capacities in terms of energy resources and buffer spaces.*

Keywords: DTN, Deployment, Routing, Mobility, Utility, Mobile nodes.

1. Introduction

Delay Tolerant Network (DTN) is characterized by the lack of end-to-end paths for a given node pair for complete periods, which poses a completely different design circumstances from that for conventional mobile ad-hoc networks (MANETs). Due to the intermittent relations in DTNs, a node is allowed to buffer a message and wait until the subsequently hop node is found to continue storing and hauling the message. Such a process is repeated until the message reaches its intention This model of routing is considerably 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 important factor for the forwarding decision of each message.

Based on the number of copies of a message that may coexist in the network, two major categories of Encounter-based routing scheme are define: single-copy and multi-copy. With the single-copy scheme, no more than a only copy of a message can be carried by any node at any instance. Although simple and resource efficient, the main confront in the implementation of single-copy schemes lies in how to effectively pact with the interruption of network connectivity and node failures. Thus, single-copy schemes have been reported to seriously suffer from long deliverance delay and/or large message loss ratio. On the other hand, multiple-copy (or multi-copy) routing schemes permit the networks to have multiple copies of the same message that can be routed autonomously and in parallel so as to increase robustness and performance. It is appeal noting that most multi-copy routing protocols are flooding-based that dispense unlimited numbers of copies throughout the network, or controlled flooding-based that distribute just a subset of significance copies, utility-based approaches that

establish whether a message should be copied to a contacted node simply based on a residential utility function.

Although improved in terms of performance, the earlier report multi-copy schemes are subject to the following problems and execution difficulties. First, these schemes predictably take a large number of transmissions, energy utilization, and a vast amount of transmission bandwidth and nodal recollection space, which could easily exhaust the network store. Second, they suffer from contention in case of high traffic tons, when packet drops could result in a significant squalor of performance and scalability. Note that the future DTNs are expected to function in an environment with a large number of minuscule hand-held devices such as mobile phones, tablet computers, personal digital assistants (PDAs), and mobile sensors. In such a scenario, it may no longer be the case that nodal contact occurrence serve as the only dominant factor for the message delivery recital as that assumed by most existing DTN prose. Therefore, limitations on power utilization, buffer seats, and user preferences should be jointly painstaking in the message forwarding procedure.

To cope with the above mentioned deficiency, a family of multi copy schemes known as utility based controlled flooding has been preferred. The class of schemes generates few copies to ensure that the network is not overloaded with the launched messages. Although being able to effectively minimize 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 enough resources for message buffering and forwarding. Any of them, to our best knowledge, has not 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 chance cost is by accepting a forwarded message; while the channel state is an indicator how likely the contact could be an eligible one; or in other words, how likely a message can be successfully sent during the contact. They are truly essential parameters to be considered in the utility function.

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

2. 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 every node. We use time-window based update strategy because it is simple in implementation and robust in opposite to parameter fluctuation. Note that the network states could change very fast and make a completely event-driven model unstable. Figure 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 4Tnew (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 current 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 all contacts, while UCUM is performed at the end of each time-window. The below subsections introduce each functional module in detail.

A. Contact Statistics (CS)

To compromise between the network state adaptability and computation complexity, every node continuously updates the network status over a fixed time window. The maintained network states are known as Contact Statistics (CS), which include nodal contact durations, channel conditions, and also 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 are in the transmission range of each other, and each transmits a pilot signal per k time units in order to look for its neighbours within its transmission range. Let T(A,B), Tfree, and Tbusy represent the total contact time, and the total amount of time the channel is free and also 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. Both 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 and (ii) the observed inter encounter time got from the current $CS^{(i)}$ (denoted as $\Delta T_{cs}^{(i)}$).

C. The Transitivity Update Module (TUM)

When two nodes are within the transmission range of each other, then they exchange utility vectors with respect to the message destination, rely on which the custodian node decides whether or not each message should be sent 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 differ 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, that is in turn based on the ratio of 4T (i) of the two encountered nodes regarding the destination rather than the 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 utility function.

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

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D.The Forwarding Strategy Module (FSM)

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

2.1 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 $\Delta T(i)(B,D) < \Delta T(i)(A,D)$l node A hands over some of the message copy tokens to node B and keeps the rest for itself.

2.2 The Forwarding Rule

If the destination node is one hop away from an encountered node, then 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, 4Tth, a custodian node hands over the message to the encountered node. The complete procedure of the forwarding strategy in SAURP is summarized as shown in Algorithm1.

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**
end else
if end for

3. Analytical Model of SAURP

Here 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 contains an ad hoc net-work with a number of nodes moving independently on a 2-dimensional torus in a geographical region, and every node belongs to a predetermined community.
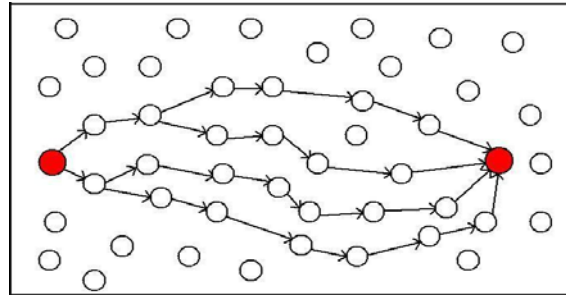
Each node can transmit up to a distance K 0 meters away, and each message forwarding (in one-hop) takes one time unit. Euclidean distance is used to measure the proximity between two nodes (or their positions) A and B. A slotted collision avoidance MAC protocol with Clear-to-Send (CTS) and Request-to-Send (RTS) is implemented for contention resolution. 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 this analysis include the average delivery probability and the message delivery delay. The analysis is depending on the following assumptions. Nodes mobility is independent and heterogeneous, where nodes have frequent appearance in some regions. Each node in the network maintains at least one forwarding path to every other node. Figure 1 illustrates the paths that a message copy may take to reach the destination. Each node is a property of 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.

3.1 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, h1 h2....hk–1, D}, and {e1, e,...., ek}, respectively. The cost on each edge, denoted as {ß1 < ß2 < .. < ßk}, 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 {ß1 < ß2 < .. < ß k}. The path cost, PRl(t), is the probability that a message m is successfully forwarded from S to D along path l within time t, that 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 which is calculated as:

$$P_{\mathrm{rl}}(t) = p_1(t) * p_2(t)* \dots p_k(t) \quad (1)$$

4. Performance Evaluation

A.Experimental Setup
To evaluate the SAURP, a DTN simulator similar to that in is implemented. The simulations are depend 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 information come 2006 experiment. The problem setup consists of an ad hoc network with a

number of nodes moving independently in a geographical location, and every 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 calculated under different network scenarios and is compared with some previously reported schemes listed below.

B. CBMM Scenario

Evaluation Scenarios: In the simulation, 110 nodes move according to community based mobility model in a 600 x 600 meter network in a given geographical location. The simulation duration is 40,000 times. 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. Every source node selects a random destination node, starts generating messages to it during simulation time.

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. Third, with respect to the average level of connectivity and varying traffic load. Fourth, the performance of protocols is calculated in terms of the bandwidth. Finally, the performance of the protocols is examined in terms of the level of connectivity changes.

5. Conclusion

The paper introduced a novel multi-copy routing scheme, known as SAURP, for intermittently connected mobile networks which are possibly formed by densely distributed and hand-held devices such as smart phones and personal digital assistants. SAURP wants 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 both wireless link condition and nodal buffer availability are considered. We provided an analytical model for SAURP, whose correctness was further checked via simulation. Now we compared SAURP with a number of counterparts via extensive simulations. It was clearly 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.

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