Contention Aware Routing for Intermittently Connected Mobile Networks

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***Abstract*—This paper introduces 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 miniature devices such as smart phones, hand-held devices, and sensors mounted in fixed or mobile objects. 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. The paper argues and proves that the nodal movement and the predicted collocation with the message recipient can serve as meaningful information to achieve an intelligent message forwarding decision at each node. The proposed protocol has been implemented and compared with a number of existing 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 the proposed SAURP outperforms all the counterpart multi-copy encounter-based routing protocols considered in the study.**

***Keywords*-Encounter based Routing, DTN.**

I. Introduction

Delay Tolerant Networks (DTNs) [1] are characterized by the lack of end-to-end paths for a given node pair for extended periods, which demonstrates a complete different design scenario from that for the conventional mobile ad-hoc networks (MANETs) [13]. Due to the intermittent connections in DTNs, a node is allowed to buffer a message and wait until it finds an available link to the next hop that will be able to store the message. Such a process is repeated until the message reaches its destination. This model of routing constitutes a significant difference from that employed in the MANETs, which 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 [5], 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 efficiently deal with interruptions of network connectivity and node failures. Thus, single-copy schemes have been reported to seriously suffer from long delivery delay 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 a common message that can be routed independently and in parallel so as to increase robustness and performance. It is worth of noting that most multi-copy routing protocols are flooding-based [3], [4] that distribute unlimited numbers of copies throughout the network, or controlled flooding-based [20] that distribute just a subset of message copies, or utility-based approaches [2] that determines 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 respective problems and implementation difficulties. First of all, these schemes inevitably take a large amount of nodal energy, transmission bandwidth, and nodal memory space, which could easily dominate the network resource consumption. In addition, they suffer from contention in case of high traffic loads, in which packet drops could result in a significant degradation of performance and scalability. Note that the future DTNs are expected to operate on a vast number of miniature and hand-held devices such as smart phones, tablet computers, personal data assistants (PDAs), and fixed/mobile sensors, which are subject to a stringent limitation on power consumption and computation resources.

To cope with the deficiency of single-copy and multi-copy schemes, a family of multi-copy schemes called Spray routing [15], [6], [21], [14] was 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 Spray routing schemes have been reported to effectively reduce the message delivery delay and the number of transmissions, all of them assume that each node has sufficient resources for message buffering and forwarding. None of them have investigated how the protocol should take advantage of dynamic network status to improve the performance, such as packet collisions, wireless link conditions, and nodal buffer occupancy. There is obviously some room to improve for the Spray routing schemes in the DTN scenario considered in this study.

With this in mind, we introduce a novel DTN routing

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protocol, called Self Adaptive Utility-based Routing Protocol (SAURP) that overcomes the shortcomings of the previously reported multi-copy schemes. The main feature of the proposed protocol is the strong capability in adaptation to the fluctuation of network status, traffic patterns/characteristics, and user behaviors, so as to reduce the number of transmissions, message delivery time, and increase delivery ratio. This is achieved by jointly considering node mobility statistics, congestion, and buffer occupancy, which are subsequently fused in a novel quality-metric function. In specific, the link availability and buffer occupancy statistics are obtained by sampling the channels and buffer space during each contact with another node. The developed quality-metric function targets to facilitating decision making for each active data message, resulting in optimized network performance. We will show via extensive simulations that the proposed SAURP can achieve a significant performance gain over the previously reported counterparts.

The rest of the paper is organized as follows. Section II provides related work. Section III describes the proposed SAURP in detail. Then, Section IV provides the simulation results and the comparisons with the other counterparts. In Section V, we conclude the paper.

II. Related work

The previously reported encounter-based routing protocols have focused on the node mobility which is exploited and taken as the dominant factor in the message forwarding decision. Those schemes contributed by introducing novel interpretations of the observed node mobility in the per-node utility function. Spyropoulos et al. in [12], [6] developed routing strategies using different utility routing metrics based on nodal mobility statistics, namely Most Mobile First (MMF), Most Social First (MSF) and Last Seen First (LSF). Lindgren et al. in [2] introduced a routing technique in DTNs which takes advantage of the predicted encounter probability between nodes. Jones et al. in [19] introduced a utility function for DTN routing which manipulates the minimum expected inter-encounter duration between nodes. Ling et al. in [23] designed a feedback adaptive routing scheme based on the 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. Some DTN message forwarding techniques [22],[24] have considered available bandwidth and buffer status in the routing metric to decide which message to replicate first among all messages in custodian buffer. The derivation of the routing metric, nonetheless, is not related to channel condition status.

Another scheme is called delegation forwarding [14], 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 [17] 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. 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 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. An approach very similar to the Spray and Focus protocol was proposed by Li et al. [7], which differs from that by [6] in the employed utility function and queuing policy mechanisms. In specific, the utility function in is designed based on the probability of the duration of the contact time between pairs for a given time window interval.

Although some studies improved the previously reported designs by overcoming some of the shortages [6], [7], [2], [14], they are subject to various limitations in the utility function updating processes. These limitations are addressed in our previous work in [15]. More importantly, the channel capacity and buffer occupancy states have never been considered in the derivation of utility functions. These two factors could be overlooked/ignored if the encounter frequency is low, where the routing protocol performance is dominated by node mobility, while the network resource availability does not plays an important role. However, in the scenario that the nodal encounter frequency is large and each node has many choices for packet forwarding, the network resource availability could become a critical factor for improving routing protocol performance, and should be taken seriously in the derivation of utility functions.

Motivated by above observations, this work investigates encounter based routing technique that jointly considers node mobility and the network states, including wireless channel and buffer occupancy. This work proposes other strategies that can use fewer copies than the Spray and Focus scheme by spreading a number of copies that is less than or at most equal to the number of copies used in the Spray and Focus scheme, while obtaining better guaranteed results than those of other schemes described in the literature.

III. Self Adaptive Utility-based Routing Protocol (SAURP)

The most distinguished characteristic of SAURP is its ability of adapting itself to the observed network behaviors in order to reduce the number of transmissions, the message delivery time, and the delivery ratio. This is made possible by employing an efficient strategy for achieving a time-window based update

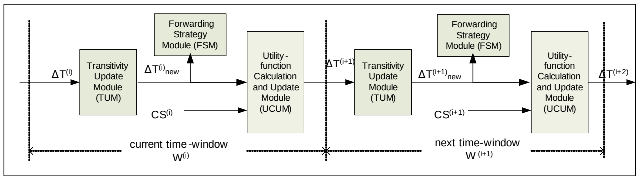

Figure 1. The SAURP Architecture

mechanism for some network status parameters at each node. We use time-window based update strategy because it is simple in implementation and rather 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 $CS^{(i)}$) is obtained at each node regarding the total nodal contacts 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 as $\triangle T_{new}^{(i)}$, which is obtained by feeding $\triangle T^{(i)}$ 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. $\triangle T^{(i+1)}$ is the output of UCUM, and is calculated at the end of current time window $W^{(i)}$. $\triangle T^{(i+1)}$ is thus used in time window $W^{(i+1)}$ for the completely the same tasks as in window $W^{(i)}$.

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

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 within 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 will be 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 broadcasts a pilot signal per k time units in order to look for its neighbors 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:

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

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 ($\triangle T^{(i)}$), which is calculated according to the previous time-window utility (i.e., $\triangle T^{(i)}$), as well as an update process via the transitivity property update (introduced in subsection 3.3), and (ii) the observed inter-encounter time obtained from the current $CS^{(i)}$ (denoted as $\triangle T_{cs}^{(i)}$).

1) Calculation of Inter-encounter Time ($\triangle T^{(i)}$): 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 T_{free} during time window $W^{(i)}$, the number of eligible contacts in the time window is determined by:

$$n_c = \left\lfloor \frac{T_{free}}{T_p} \right\rfloor \tag{2}$$

where T_p is the least time duration required to transmit a single message. Let $\triangle T_{cs(A,B)}^{(i)}$ denotes the average inter-encounter time duration of node A and B in time window i. Obviously, $\triangle T_{(A,B)}^{(i)} = \triangle T_{(B,A)}^{(i)}$. We have the following expression for$\triangle T_{cs(A,B)}^{(i)}$:

$$\triangle T_{cs(A,B)}^{(i)} = \frac{W}{n_c} \tag{3}$$

$\triangle T^{(i)}{}_{cs(A,B)}$ describes how often the two nodes encounter each other per unit of time (or, the encounter frequency) during time window 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. With this, the proposed routing protocol does not presume any knowledge of future events, such as node velocity, node movement direction, instants of time with power on or off, etc; instead, each node keeps network statistic histories with respect to the inter-encounter frequency of each node pair (or, how often the two nodes encounter each other and are able to perform an 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., n_c) and the contact time (i.e., T_{free}). 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., $\triangle T_{cs}^{(i)}$), and the other is from the previous time window parameters (i.e., $\triangle T^{(i)}$), in order to achieve a smooth transfer of parameter evolution. The following equation shows the derivation of $\triangle T^{(i+1)}$ in our scheme.

$$\triangle T^{(i+1)} = \gamma.\triangle T_{cs}^{(i)} + (1-\gamma)\triangle T^{(i)} \tag{4}$$

The parameter β is given by

$$\gamma = \frac{\mid \triangle T^{(i)} - \triangle T_{cs}^{(i)} \mid}{max(\triangle T^{(i)}, \triangle T_{cs}^{(i)})},\ \triangle T^{(i)},\ \triangle T_{cs}^{(i)} > 0 \tag{5}$$

The above relation is hold even if $\triangle T^{(i)} \geq W$ and $\triangle T_{cs}^{(i)} \geq W$ which represents the worst case scenario, i.e. unstable node behavior, low quality of node mobility, or very congested area.

$\triangle T^{(i+1)}$ represents the routing metric 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, and the vector is called *routing metric table*. The routing metric table can be employed in the decision making process for message forwarding.

C. The Transitivity Update Module

When two nodes are within transmission range of each other, they exchange utility vectors regarding the message destination. With the update, the custodian node decides whether or not the message should be forwarded to the encountered node. This exchange of summary vectors is followed by another update, called transitivity update. Although the idea of using transitivity and time-window updates are not new [2], [19], the proposed SAURP has gone through a much different way. The transitivity property [2] based on the observation that if node A frequently encounters node B and B frequently encounters node D, then A has good ability to forward messages to D through B. We formulated the updating rule as follows:

$$\triangle T_{(A,D)new}^{(i)} = \alpha \triangle T_{(A,B)}^{(i)} + (1-\alpha)(\triangle T_{(A,B)}^{(i)} + \triangle T_{(B,D)}^{(i)}) \tag{6}$$

where w is weighting factor that must be less than 1 to be valid.

$$\alpha = \frac{\triangle T_{(A,B)}^{(i)} + \triangle T_{(B,D)}^{(i)}}{\triangle T_{(A,D)}^{(i)}},\ \triangle T_{(A,D)}^{(i)} > \triangle T_{(A,B)}^{(i)} + \triangle T_{(B,D)}^{(i)} \tag{7}$$

α has a significant impact on the routing decision rule. From 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. Thus, a transitivity property is needed to update values only when $\triangle T_{(A,D)}^{(i)} > \triangle T_{(B,D)}^{(i)}$ in order to ensure that node A reaches D through B. Otherwise, if $\triangle T_{(A,D)}^{(i)} < \triangle T_{(B,D)}^{(i)}$, the transitivity property is not useful since node A is a better candidate for forwarding messages directly 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 goodness of the encountered node regarding the destination, and the number of message copy tokens. If the message tokens greater than 1, weighted copy rule is applied, the forwarding rule is applied otherwise.

1) The Weighted Copy Rule : The source of a message initially starts with L copies; any node A that has $n > 1$ message copy tokens (source or relay) and that encounters another node B with no copies and $\triangle T_{(B,D)}^{(i)} < \triangle T_{(A,D)}^{(i)}$, node A hands over to node B a number of copies according to its goodness for the destination node D. Node A hands over some of the message copy tokens to node B and keeps the rest for itself according to the following formula:

$$N_B = \left\lfloor N_A \left(\frac{\triangle T_{(A,D)}^{(i)}}{\triangle T_{(B,D)}^{(i)} + \triangle T_{(A,D)}^{(i)})} \right) \right\rfloor \tag{8}$$

where N_A is the number of message tokens that node A has, $\triangle T_{(B,D)}^{(i)}$ is the inter-encounter time between node B and node D, and $\triangle T_{(A,D)}^{(i)}$ 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 destination node. After L messages have been copied to custodian nodes, each of the L nodes carrying a copy of the message performs according to the forwarding rule as descried next.

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.
- 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, $\triangle T_{th}$, 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.

IV. Performance Evaluation

In this section a statistical analysis is conducted on the performance of the proposed SUARP. 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 $K \geq 0$ meters away, and each message transmission takes one time unit. Euclidean distance is used to measure the proximity between two nodes (or their positions) A and

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
  if $\triangle T^{(i)}_{(A,D)} > \triangle T^{(i)}_{(B,D)}$ *do*
    if message tokens >1 *then*
      apply weighted copy rule
    end if
    else if $\triangle T^{(i)}_{(A,D)} > \triangle T^{(i)}_{(B,D)} + \triangle T_{th}$ *then*
      A forwards message to B
    end if
  end if
end for

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 of SAURP is examined under different network node connectivity scenarios and is compared to some previously reported schemes listed below.

- Epidemic routing (epidemic) [3]
- Spray and Focus (S&F) [6]
- Most mobile first (MMF)[25]
- Delegation forwarding (DF) [14]
- Self-Adaptive utility-based routing protocol (SAURP)

A. Evaluation Scenarios

In the simulation, 110 nodes move according to the community-based mobility model [6] in a 600 x 600 2-dimensional torus in a given geographical region. 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.

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. Finally, with respect to the moderate-level of connectivity and varying traffic load.

1) Impact due to Number of Message Copies : We firstly look into impact of the number of message copies toward the performance of each protocol. The transmission range K of each node is set to 40 meters, leading to a relatively sparse network. In order to reduce the effect of contention on any shared channel, the traffic load and buffer capacity is set to medium (i.e., 40 generated messages per node in 40,000 time units) and high (i.e. 1000 messages), respectively. The number of message copies is then increased from 1 to 20 in order to examine their impact on the effectiveness of each protocol.

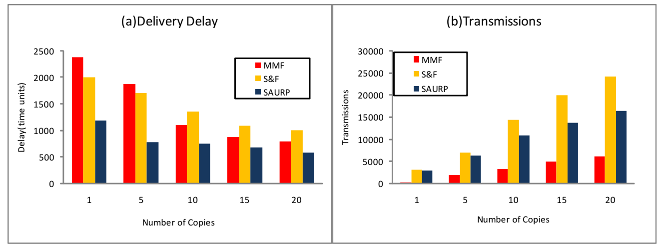

Figure 2. Impact of the number of message copies

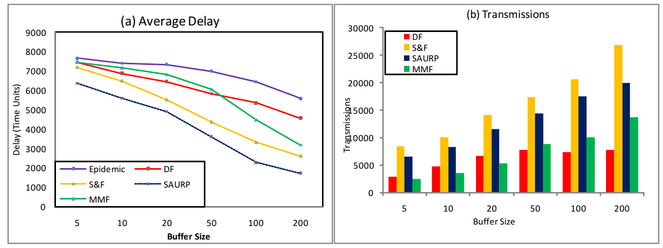

Figure 3. The effect of buffer size

The proposed SAURP is compared with the S&F and MMF schemes, since each scheme has a predefined L to achieve the best data delivery. Note that the value of L depends on the application requirements, the mobility model considered, and the design of the protocol.

Fig. 2 shows the results on message delivery delay, and number of transmissions under different numbers of copies of each generated message. As can be seen, the L value has a significant impact on the performance of each scheme. It is observed that best performance can be achieved under each scheme with a specific value L. These L values can serve as a useful rule of thumb for producing good performance.

2) The Effect of Buffer Size: In this scenario the performance of SAURP regarding different buffer sizes is examined under a low transmission range (i.e., K = 30) and a high traffic load (i.e., 70 messages generated per node in 40,000 time units). Due to the high traffic volumes, we expect to see a significant impact upon the message forwarding decisions due to the degradation of utility function values caused by buffer overflow. Note that when the buffer of the encountered node is full, some messages cannot be delivered even though the encountered node metric is better than the custodian node. This situation results in extra queuing delay, especially in the case that flooding-based schemes are in place. Fig. 3 shows the experiment results where the buffer space was varied from 5 (very limited capacity) to 200 (relatively high capacity) messages to reflect the performance of the protocols under the considered traffic load. As shown in Fig. 6, when the buffer size is small (50 messages or less) the performance of the protocols is very sensitive to the change of buffer capacity.

It is observed that Epidemic routing produced the worst delivery delay in all scenarios, since it has been critically affected by both the limited buffer size and mobility model. On the other hand, since SAURP takes the situation that a node may have a full buffer into consideration by degrading the corresponding utility metric, it produced the best performance. In specific, SAURP yielded a shorter delivery delay than DF

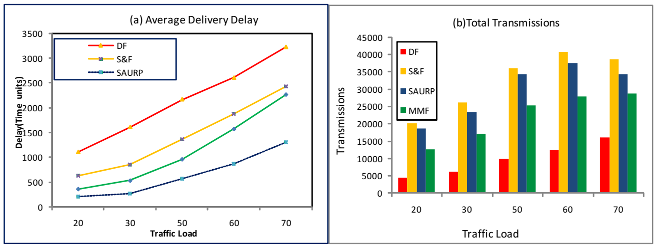

Figure 4. The effect of traffic load under high buffer capacity

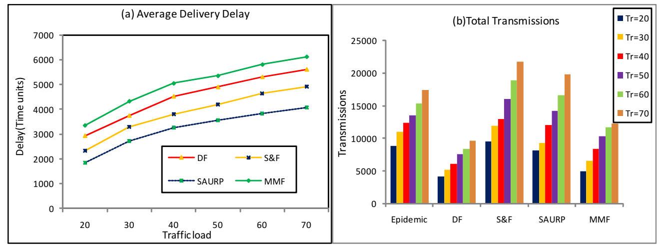

Figure 5. The effect of traffic load under low buffer capacity

by 40%, and a higher delivery ratio than DF by 80%. Although SUARP produced more transmissions than MMF, it yielded a smaller delivery delay than that of MMF by 70%. As the buffer size increased, the performance of all protocols was improved especially for MMF. When the buffer size is larger than the traffic demand, the MMF scheme has yielded a competitive performance due to the relaxation of buffer capacity limitation. SAURP still yielded the best performance with a smaller number of transmissions than S&F by 37%.

3) The Effect of Traffic Load : The main goal of this scenario is to observe the performance impact and how SAURP reacts under different degrees of wireless channel contention. The network connectivity is kept high (i.e., the transmission range is set to as high as 70 meters) under different traffic loads, while channel bandwidth is set relatively quite small (i.e., one message transfer per unit of time) in order to create an environment with non-trivial congestion. We have two scenarios for nodal buffer capacity: 1) unlimited capacity; and 2) low capacity (15 messages). Fig.7 shows the performance of all the routing algorithms in terms of the average delivery delay, delivery ratio, and total number of transmissions.

It is observed that Epidemic routing produced the largest delivery delay and requires a higher number of transmissions compared to all the other schemes, thus it is not included in the figure. Note that the Epidemic routing is subject to at least 3 times of longer delivery delay than that by S&F and an order of magnitude more transmissions than that by SUARP.

As shown in Fig. 4(a), and 4(b), when the traffic load is increased, the available bandwidth is decreased accordingly, which causes performance reduction. When the traffic load is moderate (i.e., less that 50 messages in 40,000 time units), it is clear that the delivery delay is short in all the schemes, while SAURP outperforms all other protocols and MMF is the second best. This is because in MMF, the effect of buffer size is relaxed, which makes nodes buffer an unlimited number of messages while roaming among communities. SAURP can produce delay shorter than that of MMF, DF, S&F by 52%, 400%, and 250%, respectively. Regarding the delivery ratio, SAURP, MMF, and S&F can achieve excellent performance of 98%, while the epidemic routing degrades below 40% for high traffic loads. DF can achieve delivery ratio above 92%.

As expected, the performance of all the schemes degrades as wireless channel contention is getting higher especially when the traffic load exceeds 50 messages per node during the simulation period 40,000 time units. We observed that SAURP can achieve significantly better performance compared to all the other schemes, due to the consideration of busy links in its message forwarding mechanism, where the corresponding routing-metric is reduced accordingly. This results in the ability of rerouting the contended messages through the areas of low congestion. However, such a rerouting mechanism makes messages take possibly long routes and results in more transmissions than that of MMF. In summary, the delivery delay obtained by the SAURP in this scenario is shorter than that of MMF by 70% , S&F by 90%, and DF by 247%, respectively.

As the buffer capacity is low (e.g. 15 messages) and the traffic load is high, the available bandwidth decreases and the buffer occupancy increases accordingly, which makes the performance of all protocols degraded, especially for MMF. It is notable that SUARP outperforms all the multiple-copy routing protocols in terms of delivery delay and delivery ratio under all possible traffic loads. When the traffic load is high, SAURP yielded shorter delivery delay than that of MMF by 52%, SF by 30%, and DF by 40%. Although SAURP requires more transmissions compared to the MMF and DF, the number is still smaller than that produced by S&F. Fig. 5(a), and 5(b) shows the performance of all techniques under this scenario.

V. Conclusion

The paper introduced a novel multi-copy routing scheme called SAUPR, for intermittently connected mobile networks. SAURP is characterized by the ability of identifying potential opportunities for forwarding messages to their destinations via a novel utility function based mechanism, in which a suite of environment parameters, such as wireless channel condition, nodal buffer occupancy, and encounter statistics is jointly considered.

Thus, SAURP can reroute messages around nodes experience either high buffer occupancy, wireless interference, or congestion, while taking considerably smaller number of transmissions. We verified the proposed SAURP via extensive simulation and compared it with a number of counterparts. SUARP has shown great stability and achieved 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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