Sporadic Associated Mobile Networks with Auto Adjust Dispute Realisation Routing Protocol

S. Sivakumar[1], Dr. S. Sivasubramanian[2] and P. Sathish Saravanan[3]

Abstract— For Delay Resistant Networks that are perhaps compiled of an immense number of devices in miniature such as smart phones of heterogeneous capacities in price of energy resources and buffer spaces, this paper introduces a modern multi-copy routing protocol, called Auto Adjust Utility-based Routing Protocol (AAURP). An entourage of environment parameters, such as wireless channel condition, nodal buffer occupancy, and encounter statistics, are collectively considered to characterize AAURP for the ability to name possible chances for forwarding messages to the destination via a modern function utility based mechanism. Thus, AAURP can reroute messages around nodes feeling high buffer occupancy, wireless noise and congestion, while taking a substantially small amount of transmissions. In AAURP, the developed utility function is proved to be able to achieve optimal performance, which is further examined via a random modelling approach. To verify the formulated analytical model and compare the suggested AAURP wide simulations are conducted with a number of recently reported encounter-based routing approaches in terms of delivery ratio, delivery delay, and the number of transmissions needed for the message delivery. The simulation results show that AAURP outstrips all the counterpart multi-copy encounter-based routing protocols conceived in the study.

Index Terms— DRN, Encounter-based Routing, FSM, MMF, MSF, TSM, UCMM.

◆

1 INTRODUCTION

Delay Resistant Network (DRN) [5] is assessed up by the lack of end-to-end paths for a given node pair for extended periods, which poses a completely different design premise from that for conventional mobile adhoc networks (MANETs) [12]. Due to the sporadic connections in DRNs, 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 substantially different from that employed in the MANETs. DRN 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 substantial element for the forwarding decision of each message.

Depending on the number of copies of a message that may coexist in the network, two major classes of encounter-based routing strategies are defined: single-copy and multi-copy. With the single-copy strategies [3], 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 effectuation of single-copy strategies lies in how to effectively deal with the disruptions of network connectivity and node failures. Thus, single-copy strategies 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 strategies allow 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 worth noting that most multi-copy routing protocols are flooding-based [2], [1] that disseminate unrestricted numbers of copies throughout the network, or assured flooding-based [19, 8] that disseminate just a subset of message copies, or utility-based advances [4] that determine whether a message should be copied to a contacted node simply based on a formulated utility function.

Although improved in terms of performance, the previously reported multi-copy strategies are field to the following problems and effectuation difficulties. First, these strategies inevitably take a large number of transmissions, energy consumption, and an immense amount of transmission bandwidth and nodal memory space, which could easily exhaust the network resource. Second, they suffer from disputation in case of high traffic loads, when packet drops could result in a substantial debasement of functioning and measurability. Note that the future DRNs are anticipated to operate in surroundings 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 prevalent element for the message delivery functioning as that assume d by most existing DRN literature. Therefore, restrictions on power consumption, buffer spaces, and user preferences should be jointly conceived in the message forwarding process.

IJSER staff will edit and complete the final formatting of your To cope with the above mentioned inadequacy, a family of multi-copy strategies called utility-based assured flooding [11, 25, 13, 14] has been suggested. The class of strategies generates only a small number of copies to ensure that the network is not overloaded with the launched

---

- [1]*He is currently working as Associate Professor in Dept. of I.T., Dhanalakshmi College of Engineering, Chennai, India.*
E-mail: sivas.postbox@gmail.com
- [2]*He is currently working as Professor and Principal in Dhanalakshmi College of Engineering, Chennai, India.*
E-mail: drsivamdu2011@gmail.com
- [3]*He is currently working as Assistant Professor in Dept. of I.T., Dhanalakshmi College of Engineering, Chennai, India.*
E-mail : psathishsaravanan@gmail.com

messages. Although being able to effectually reduce the message delivery delay and the number of transmissions, most of the utility-based assured flooding routing strategies in literature assume that each node has adequate resources for message buffering and forwarding. None of them, to our best cognition, has adequately looked into how the protocol should take advantage of dynamic network status to improve the performance, such as packet collision statistics, wireless link status, 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 status is an indicator how likely the contact could be an entitled one; or in other words, how likely a message can be successfully forwarded during the contact. They are obviously essential parameters to be conceived in the utility function.

2 RELATED WORK

Most (if not all) previously reported encounter-based routing strategies have focused on nodal mobility, which has been widely exploited as the prevalent element in the message forwarding decision. Those strategies contributed in the context of introducing new interpretations of the noticed node mobility in the per-node utility function. Psounis et al. in [10, 14] formulated 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). Bakht et al. [26] suggested an enhanced version of MSF by taking the number of message replicas transferred during each contact in proportion to the per-node utility function, which is in turn determined by the evolution of the number of nodal finds during each time-window. Lindgren et al. in Lily Li et al. in [20] acquainted a modern utility function for DRN routing by controlling the minimum anticipated inter-encounter duration between nodes. Wu Wei et al. in [22] designed a feedback adjust routing scheme based on the determine components solely determined by the node mobility; where a node with higher mobility is given a higher element, and messages are transmitted through nodes with higher determine components.

A. Doria et al. in [4] acquainted a DRN routing scheme which predicts encounter probability between nodes. Gallagher et al. in [36] acquainted a routing protocol which bases its decisions on whether to transmit or delete a message on the path likeliness. The path likeliness metric is based on historic information of the number of finds between nodes. Y. Liao et al. in [37] acquainted a routing scheme that combines erasure-coding 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 components such as buffer occupancy, and available battery power level.

B. Levine et al. in [23] acquainted a routing scheme as resource allocation. The statistics of available bandwidth and the number of message replicas currently in the network are conceived in the 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. Along the similar line of research, Barakat et al. in [41] suggested a forwarding and dropping policy for a restricted buffer capacity. The decision under this policy is made based on the value of per-message marginal utility. This policy none the-less was designed to suit homogeneous nodal mobility. Y. Yi et al. in [40] acquainted a comprehensive routing scheme as resource allocation that jointly optimizes link scheduling, routing, and replication. This framework allows the formulated solutions to be adjusted to various network status s regarding nodal encumbrances and connections / disconnections. Zhang et al. in [38] acquainted a routing scheme based on calculating the anticipated 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 called delegation forwarding was acquainted in [13], 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 finds between node pairs) of the encountered node is higher than all the nodes so far “seen” by a message, and then current custodian will modify its utility value of that message to be equal to that of the encountered node. Psounis et al. in [10] suggested routing scheme called Spray and Focus, which is assessed up 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 finds 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 it. 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 substantially reduce the required number of transmissions, while achieving a competitive delay with respect to network contentions such as buffers space and bandwidth.

Some studies have looked into the impact of human mobility and their social relations on the routing algorithms [34, 35, 34, 33, 32, 16, 42] leading to a class of social network based message forwarding schemes. With these schemes, the variation in node popularity and the detectability of communities are employed as the main components in the forwarding decisions. Bubble-rap [31] is a representative protocol by conceiving the importance of individuals in a social network for making the message forwarding decision. Mascolo et al. in [16] acquainted a DRN routing scheme using utility functions 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 a given destination. Other strategies are based on content-based network service [39] as a modern style of communication that associates source and destination pairs based on actual content and interests, rather than by letting the source to specify the destination.

Although previously reported studies such as [10, 8, 4, 13, 32, 23] have made great efforts in improving the DRN routing techniques, they are field to various restrictions in the utility function modify processes. The strategies such as [4, 37] that take the number of finds as the main element in the message forwarding decision, may suffer from multiple falsely detected contacts. This happens when a node exhibits an sporadic connection with another node, e.g., due to a communication barrier. Further, a permanent or quasi-permanent neighbor will cause the utility function calculation invalid in message forwarding. For example, if node A and B remain in the transmission range of each other for a long period without disconnection, there will be only one contact counted between the two nodes irrespective of the long duration of the contact. A routing decision based on the number of contacts makes node B a less suitable candidate for carrying a message from node A than other nodes that have a larger number of contacts, even though node B could actually be the preferred candidate for carrying the messages.

Although the abovementioned strategies can capture the mobility properties in order to come up with effectual forwarding Scheme, they may not be able to acquire accurate cognition about network dynamics and unpredicted contacts. More importantly, the channel capacity and buffer occupancy status have never been jointly conceived in the derivation of utility functions for hop-by-hop message forwarding. It is clear that these two components could only be overlooked/ignored when the encounter frequency is low since the routing protocol functioning is prevailed by node mobility, while the network resource availability does not play an important role. However, in the premise that the nodal encounter frequency is large and each node has many choices for message forwarding in a short time, the network resource availability is visualized to serve as a critical element for functioning improvement and should be utilized in the derivation of utility functions.

Motivated by the above observations, this paper enquires encounter-based routing that jointly conceives nodal contact statistics and network status including wireless channel status and buffer occupancy. Our goal is to reduce the delivery delay and the number of transmissions under stringent buffer space and link capacity restraints. This is a desired feature of a DRN particularly in the premise where each mobile node is hand-held device with restricted resources.

3 AUTO ADJUST UTILITY-BASED ROUTING PROTOCOL (AAURP)

The suggested AAURP is assessed up by the power of adapting itself to the noticed network behaviors, which is made possible by employing an effectual time-window based modify mechanism for some network status parameters at each node. We use time-window based modify Scheme because it is simple in effectuation and robust against parameter fluctuation. Note that the network status could change very fast and make a completely event-driven model unstable. Figure 1 illustrates the functional modules of the AAURP architecture along with their relations.

The Contact Statistics (denoted as $CS^{(i)}$) refers to the statistics of total nodal contact durations, channel status , 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 Modify Module (UCMM). Another input to the UCMM, as shown in Fig. 1, is the updated utility denoted by $\Delta T^{(i)}_{new}$, which is found by feeding $\Delta T^{(i)}$(the inter-contact time between any node pair, A and B) through the Transitivity Modify Module (TMM). UCMM is applied such that an adjust and smooth transfer between two sequential time windows (from current time-window to next time-window) is asserted. $\Delta T^{(i+1)}$ is the output of UCMM, and is calculated at the end of current time window $W^{(i)}$. $\Delta T^{(i+1)}$ is thus used in time window $W^{(i+1)}$ for the same tasks as in window $W^{(i)}$.

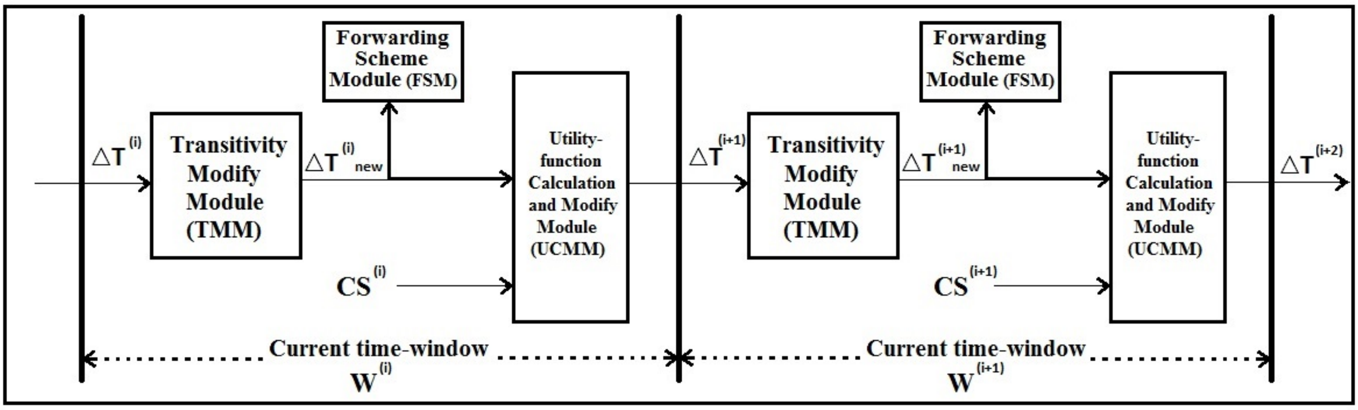


Fig. 1. AAURP Architecture

Forwarding Scheme 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., $\Delta T^{(i)}$).

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

3.1 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 asserted network states are referred to as Contact Statistics (CS), which include nodal contact durations, channel status, and buffer occupancy state, and are fed into UCMM 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 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:

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

Note that the total contact time could be collected over multiple contacts between A and B during $W^{(i)}$.

3.2 Utility-function Calculation and Modify Module (UCMM)

UCMM is applied at the end of each time window and is used to calculate the currently noticed utility that will be further used in the next time window. The two inputs to UCMM in time window $W^{(i)}$ are: (i) the predicted inter-contact time ($\Delta T^{(i)}$), which is calculated granting to the previous time-window utility (i.e., $\Delta T^{(i)}$), as well as an modify process via the transitivity property modify (acquainted in subsection 3.3), and (ii) the noticed inter-encounter time found from the current $CS^{(i)}$ (denoted as $\Delta T_{cs}^{(i)}$).

3.2.1 Calculation of Inter-encounter Time ($\Delta T^{(i)}$)

An entitled 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 finds B for a total time duration T_{free} during time window $W^{(i)}$, the number of entitled contacts in the time window is determined by:

$$n_c^{(i)} = \left\lfloor \frac{T_{free}}{T_p} \right\rfloor \qquad (2)$$

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

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

$\Delta T_{cs(A,B)}^{(i)}$ describes how often the two nodes encounter each other per unit of time (or, the encounter frequency) during time window $W^{(i)}$ conceiving 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 anticipated to better ponder the likeliness that nodes will meet with each other for effectual message exchange.

With this, the suggested routing protocol does not assume any cognition of future events, such as node velocity, node movement direction, instants of time with power on or off; rather, each node holds 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 effectual message exchange).

3.2.2 Time-window Transfer Update

Another important function provided in UCMM is for the smooth transfer of the parameters between sequential time windows. As discussed earlier, the connectivity between any two nodes is assessed granting 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 substantial 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 noticed statistics (i.e., $\Delta T_{cs}^{(i)}$), and the other is from the previous time window parameters (i.e., $\Delta T^{(i)}$), in order to achieve a smooth transfer of parameter evolution. The following equation shows the derivation of $\Delta T^{(i+1)}$ in our scheme.

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

The parameter γ is given by

$$\gamma = \frac{\left|\Delta T^{(i)} - \Delta T^{(i)}_{cs}\right|}{\max\left(\Delta T^{(i)}, \Delta T^{(i)}_{cs}\right)}, \text{ where } \Delta T^{(i)}, \Delta T^{(i)}_{cs} > 0 \quad (5)$$

If $\Delta T^{(i)}_{cs}$ > W, which happens if if $n^{(i)}_{C} = 0$, then $\Delta T^{(i+1)} = \frac{2W}{n^{(i-1)}_{C}}$. This case represents a worst case scenario, i.e. unstable node behaviour, or low quality of node mobility. Hence, the $\Delta T^{(i+1)}$ value should be low.

$\Delta T^{(i+1)}$ represent the routing metric (utility) value that is used as input to the next time window. This value is asserted 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.

3.2.3 The Transitivity Modify Module (TMM)

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 modify [4] is initiated. We propose a modern adjust transitivity modify rule, which is different from the previously reported transitivity modify rules [4, 10]. The suggested transitivity modify rule is assessed up as follows: (1) it is adjectively modified granting to a weighting element, which is in turn based on the ratio of $\Delta T^{(i)}$ of the two encountered nodes regarding the destination rather than using a scaling constant. Note that the weighting element 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 conceiving the nodes that can effectually enhance the accuracy of the utility function.

The transitivity property is based on the observation that if node *A* frequently finds node *B* and *B* frequently finds node *D*, then *A* has a good chance to forward messages to *D* through *B*. Such a relation is implemented in the suggested AAURP using the following modify Scheme:

$$\Delta T^{(i)}_{(A,D)new} = \alpha \Delta T^{(i)}_{(A,D)} + (1 - \alpha)\left(\Delta T^{(i)}_{(A,B)} + \Delta T^{(i)}_{(B,D)}\right) \quad (6)$$

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

$$\alpha = \frac{\Delta T^{(i)}_{(A,B)} + \Delta T^{(i)}_{(B,D)}}{\Delta T^{(i)}_{(A,D)}}, \Delta T^{(i)}_{(A,D)} > \Delta T^{(i)}_{(A,B)} + \Delta T^{(i)}_{(B,D)} \quad (7)$$

α has a substantial 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 modify process, and modify should be initiated at node *A* regarding *D* only when $\Delta T^{(i)}_{(A,D)new} > \Delta T^{(i)}_{(B,D)}$. 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.

3.3 The Forwarding Scheme Module (FSM)

The decision of message forwarding in AAURP 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 copies are currently carried, the *weighted copy rule* is applied; otherwise the *forwarding rule* is applied.

3.3.1 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 finds another node *B* with no copies with $\Delta T^{(i)}_{(B,D)} < \Delta T^{(i)}_{(A,D)}$, node *A* hands over some of the message copy tokens to node *B* and holds the rest for itself granting to the following formula:

$$N_B = \left\lfloor N_A \left(\frac{\Delta T^{(i)}_{(A,D)}}{\Delta T^{(i)}_{(B,D)} + \Delta T^{(i)}_{(A,D)}} \right) \right\rfloor \quad (8)$$

where N_A is the number of message tokens that node *A* has, $\Delta T^{(i)}_{(B,D)}$ is the inter-encounter time between node *B* and node *D*, and $\Delta T^{(i)}_{(A,D)}$ 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 executes message forwarding granting 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 in [36] and our previous study [11], and has been proved to achieve improved delivery delay.

3.3.2 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, ΔT_{th}, a custodian node hands over the message to the encountered node.

The complete mechanism of the forwarding Scheme in AAURP is summarized as shown in Algorithm 1.

4 Analytical Model of AAURP

In this section a statistical analysis is conducted to evaluate the functioning of AAURP. Without loss of generality, Community-Based Mobility Model [10] is employed in the analysis. The problem setup consists of an ad hoc network with a number of nodes moving autonomously 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 forwarding (in one-hop) takes one time unit.

Algorithm 1 The forwarding strategy of AAURP

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

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 disputation 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 functioning 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 autonomous and heterogeneous, where nodes have frequent appearance in some locations.
- Each node in the network asserts at least one forwarding path to every other node. Figure 2 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.
- The inter-contact time $\Delta T_{(A,\ B)}$ between nodes A and B follows an exponential distribution with probability distribution function (PDF), $P_{\Delta T_{(A,B)}}(t) = \beta_{(A,B)}.e^{-\beta_{(A,B)}t}$, 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 [6, 29]). 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 cut off point [17]. Based on the mobility model of the nodes, the distribution of the inter-contact time can be predicted and calculated using time widow updates shown in Eq. (4).

Thus, parameter β_{AB} is calculated as $\beta_{AB} = \frac{1}{\Delta T_{(A,B)}}$.

4.1 Delivery Probability

In order to calculate the anticipated message delivery ratio, any path of message m between *S* and *D* is a *k-hop* simple path, denoted as *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_2, …., e_k}, respectively. The cost on each edge, denoted as {β_1, β_2,…., β_k}, is the inter-contact rate (or frequency) of each adjacent node pair along the path. Granting to the forwarding policy of AAURP, 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 [30] which is calculated as:

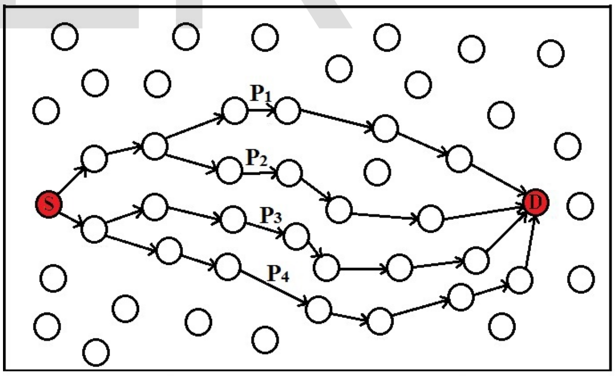


Fig. 2. Paths of message copies to destination.

$$Pr_l(t) = p_1(t) \otimes p_2(t) \otimes \ldots p_k(t) \quad (9)$$

Theorem 1. *Let the probability distribution function (PDF) for the message delivery along a one-hop path i be denoted as* $p_{(i)}(t) = \beta_i e^{-\beta_i t}$. *Thus, the PDF for a k-hop simple path l with an edge cost {β_1, β_2,…., β_k} can be expressed as*

$$Pr_l(t) = \sum_{i=1}^{k_l} C_i^{(k_l)} p_i(t) \qquad (10)$$

where the coefficients are given as follows:

$$C_i^{(k_l)} = \prod_{j=1,\, i\neq j}^{k_l} \frac{\beta_j}{\beta_j - \beta_i} \qquad (11)$$

The probability of message delivery on forwarding path *l* between any source *S*, and destination *D*, within expiration time *T* is expressed as:

$$F_l(T) = PR_l(Td_l < T) = \int_0^T Pr_l(t)dt$$

$$= \sum_{i=1}^{k_l} C_i^{(k_l)} \int_0^T Pr_l(t)dt$$

$$PR_l(Td_l < T) = \sum_{i=1}^{k_l} C_i^{(k_l)} . (1 - e^{-\beta_i T}) \qquad (12)$$

If there are *L-1* copies (excluding the message at the source) of message m traversing through *L-1* autonomous paths in the network, the maximum probability of message delivery can be written as

$$PR_{max}(T_d < T) = \max\{PR_{SD}, PR_1, PR_2, \ldots, PR_{L-1}\} \qquad (13)$$

where PR_{SD} and PR_l are random variables representing the delivery probability in case of direct message delivery between *S* and *D*, and through one of *L-1* paths, respectively. The anticipated delivery probability of message m with *L-1* copies traversing on *L-1* paths is calculated as:

$$PR(T_d < T) = 1 - PR_{SD}(T_{SD} > T) \prod_{l=1}^{L-1} (1 - PR_l(Td_l < T)) \qquad (14)$$

$$PR(T_d < T) = 1 - e^{-\beta_{SD} T} \prod_{l=1}^{L-1} \left(\sum_{i=1}^{k_l} C_i^{(k_l)} . (e^{-\beta_i T}) \right) \qquad (15)$$

By assuming *X* totally generated messages in the network, the average of the delivery probability in the network is calculated as

$$PR = \frac{1}{X} \sum_{m=1}^{x} PR_m \qquad (16)$$

4.2 Delivery Delay

Theorem 2. *The anticipated total time required to deliver a message from S to D along an individual path l can be calculated as*

$$E[D_l] = \int_0^\infty PR_l(Td_l > t) = \sum_{i=1}^{k_l} C_i^{(k_l)} . \int_0^\infty e^{-\beta_i t} dt$$

$$E[D_l] = \sum_{i=1}^{k_l} C_i^{(k_l)} \frac{1}{\beta_i} \qquad (17)$$

Let message m have *L-1* copies (excluding the message at the source) traversing on *L-1* autonomous paths. The minimum delivery delay can be written as:

$$D_{SD} = \min\{T_{SD}, Td_1, Td_2, \ldots Td_{L-1}\} \qquad (18)$$

where T_{SD} and Td_l are a random variables representing the delivery delay through direct path between *S* and *D* and through one of *L-1* paths, respectively. The anticipated delay of message *m*, $E[D_{SD}]$, can be calculated as

$$E[D_{SD}] = \int_0^\infty P(T_d > t) =$$

$$\int_0^\infty e^{-\beta_{SD} t} \prod_{l=1}^{L-1} \left(\sum_{i=1}^{k_l} C_i^{(k_l)} . e^{-\beta_i t} \right) dt$$

$$= \frac{1}{\beta_{SD}} \int_0^\infty \beta_{SD} e^{-\beta_{SD} t} \prod_{l=1}^{L-1} \left(\sum_{i=1}^{k_l} C_i^{(k_l)} . e^{-\beta_i t} \right) dt =$$

$$\frac{1}{\beta_{SD}} E\left\{ \prod_{l=1}^{L-1} \left(\sum_{i=1}^{k_l} C_i^{(k_l)} . e^{-\beta_i T_{SD}} \right) \right\},\ T_{SD} < \infty \qquad (19)$$

The above relation gives delivery delay since it is specified to T_{SD}, $T_{SD} < \infty$ and can be taken as point of reference.

The average delivery delay of message m can be calculated intuitively as:

$$E[ED_{(S,D)}] = \left[\frac{1}{L} \left(T_{SD} + \sum_{l=1}^{L-1} Td_l \right) \right] . \frac{1}{PR(T_d < T)} \qquad (20)$$

T_{SD} is included in Eq. (19) only if $T_{SD} < \infty$.

By assuming *X* totally generated messages in the network, the average delivery delay can thus be calculated as

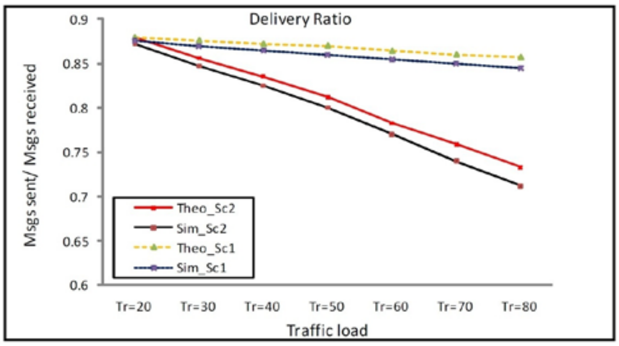
$$DR = \frac{1}{X} \sum_{m=1}^{X} D_m \qquad (21)$$

4.3 Validation of Analytical Model

In order to evaluate the accuracy of the mathematical expressions in this analysis, AAURP 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 restricted resources, i.e., the forwarding opportunities can be lost due to high traffic, restricted bandwidth, restricted buffer space, or disputation (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 granting to community-based mobility model [10] in a 300x300 network area. The transmission range is set to 30 to enable moderate network connectivity with respect to the conceived 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).

Fig. 3. The Theoretical and simulation results of delivery ratio.

Examining AAURP 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.

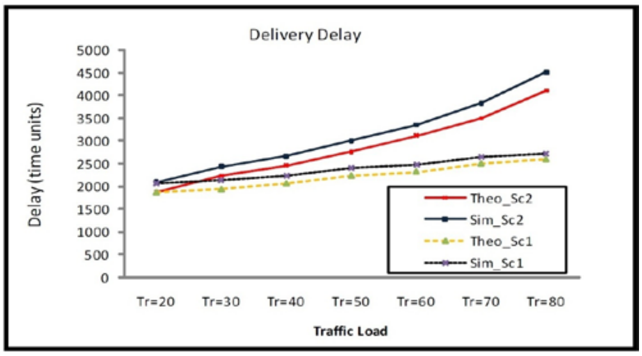
To enable accurate analysis, the simulation program is run for a period of time (warm up period of 10,000 time units) such that each node can build and assert the best forwarding paths with every other node in the network. These forwarding paths are mainly based on the congestion degree (traffic loads values) conceived 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 granting to AAURP 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-finds history if the network is not congested and the buffers operate under their capacity limit.

Figure 3 and Fig. 4 compare the theoretical and simulation results in terms of delivery ratio and delivery delay of the conceived scenarios.

As seen from the figures, when the network resources is are enough to handle all the traffic loads (Premise 1), there no dramatic change in the found delivery ratio and delivery delay for all traffic loads. That is because messages follow the best forwarding paths that lead to best performance. The simulation and analytical plots for AAURP present close match and validates the generality of the analytical expressions. Additionally, it is evident that Eq. (16) and Eq. (20) are tight for all degrees of traffic loads. When the network resources are restricted (i.e, premise 2), the disputation and the overhead of MAC layer increase which resulting in longer forwarding paths, higher drop rate, and longer delivery delay. The simulation and analytical plots are still providing close match with small diverge in case of high traffic loads.

Fig. 4. The Theoretical and simulation results of delivery delay.



Although the disputation does affect the accuracy of our theoretical expressions, the error acquainted for AAURP is not large (20%), even for large traffic loads. Therefore, we believe the analytical expression is useful in assessing the functioning in more realistic scenarios with contention. As an evident by these plots, the actual delay found by AAURP becomes increasingly worse than what the theory predicts. This demonstrates the need to add an appropriate disputation model when it comes to modelling flooding-based schemes.

5 Performance Evaluation

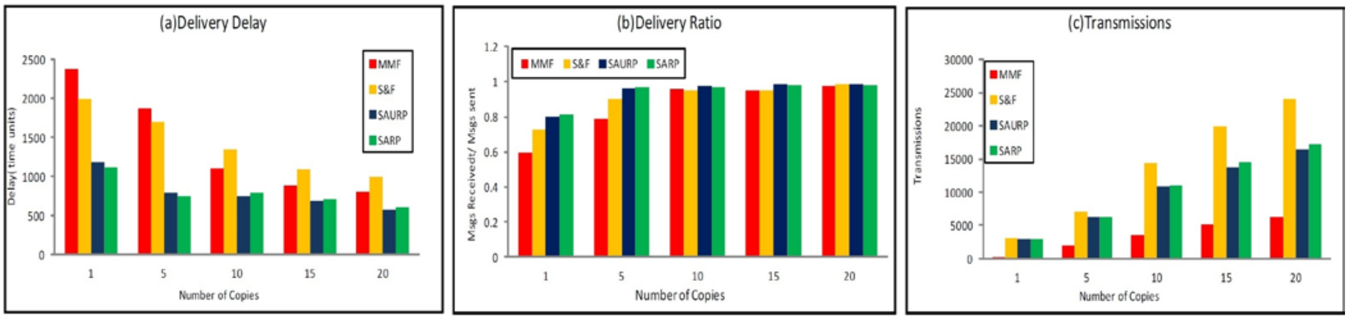
5.1 Experimental Setup

To evaluate the AAURP, a DRN simulator similar to that in [28] is implemented. The simulations are based on two mobility scenarios; a synthetic one based on community based mobility model (CBMM) [10], and real-world encounter traces collected as part of the Infocome 2006 experiment, described in [43].

The problem setup consists of an ad hoc network with a number of nodes moving autonomously 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 disputation 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 functioning of AAURP is examined under different network scenarios and is compared with some previously reported strategies listed below.

- PROPHET [2]
- Spray and Focus (S&F) [10] Most mobile first (MMF) [24]
- Delegation forwarding (DF) [13]
- Auto-Adjust utility-based routing protocol (AAURP)
- Self-Adjustive routing protocol (SARP) [11]

Fig. 5. Impact of the number of message copies.



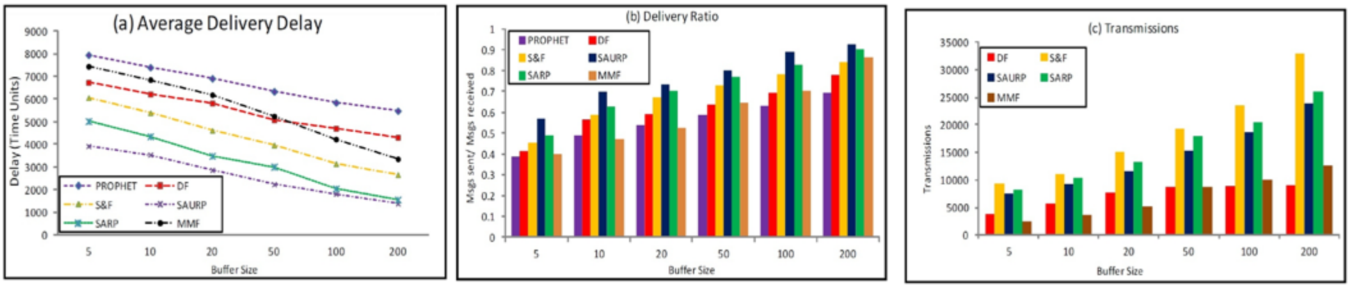


Fig. 6. The effect of buffer size.

The functioning comparison under the conceived mobility scenarios is in terms of average delivery delay, delivery ratio, and the total number of transmissions executed for all delivered messages.

5.2 CBMM Scenario

5.2.1 Evaluation Scenarios

In the simulation, 110 nodes move granting to the community-based mobility model [10] 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 analyses the functioning implication of the following. First, the functioning of the protocols is evaluated with respect to the impact of the number of message copies. Second, it is evaluated to the low transmission range and varying buffer capacity under high traffic load. Third, it is evaluated to the moderate level of connectivity and varying traffic load. Fourth, the functioning of the protocols is examined in terms of the bandwidth. Finally, the functioning of the protocols is examined in terms of the level of connectivity changes.

Impact due to Number of Message Copies

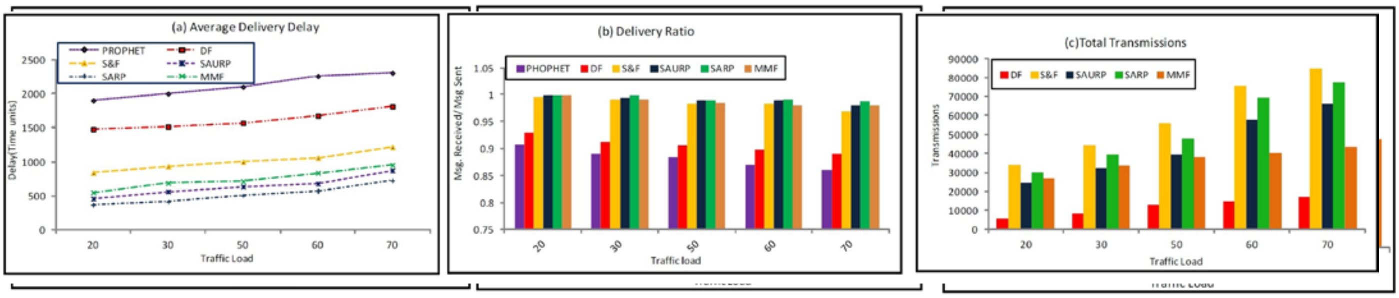
We firstly look into impact of the number of message copies toward the functioning of each protocol. The transmission range K of each node is set to 30 meters, leading to a relatively sparse network. In order to reduce the effect of disputation on any shared channel, the traffic load and buffer capacity is set to medium (i.e., 40 generated messages per node) and high (i.e. 1,000 messages per node), respectively. The number of message copies is then increased from 1 to 20 in order to examine their impact on the effectualness of each protocol. The suggested AAURP 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 conceived, and the design of the protocol.

Figure 5 shows the results on message delivery delay, delivery ratio, and number of transmissions under different numbers of copies of each generated message. As can be seen, the L value has a substantial impact on the functioning of each scheme. It is noticed that best functioning can be achieved under each scheme with a specific value L.

In the next scenarios, the number of message copies is fixed at 15 for the S&F scheme, 10 for the SARP and AAURP, and 18 for the MMF. These L values can serve as a useful rule of thumb for producing good performance.

The Effect of Buffer Size

In this premise the functioning of AAURP regarding different buffer sizes is examined under a low transmission range (i.e., K = 30) and a high traffic load (i.e., 50 messages generated per node). Due to the high traffic volumes, we expect to see a substantial impact upon the message forwarding decisions due to the debasement 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, particularly in the case that flooding based strategies are in place. Figure 6 shows the



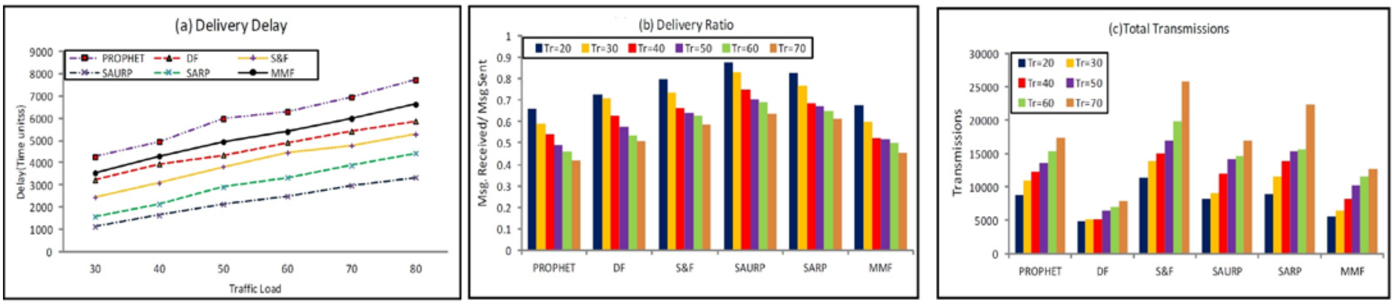


Fig. 7. The effect of traffic load under high buffer capacity.

Fig. 8. The effect of traffic load under low buffer capacity.

experiment results where buffer space was varied from 5 (very restricted capacity) to 200 (relatively high capacity) messages to ponder the functioning of the protocols under the conceived traffic load. As shown in Fig. 6, when the buffer size is small (50 messages or less) the functioning of the protocols is very sensitive to the change of buffer capacity.

It is noticed that the AAURP scheme produced the best functioning in all scenarios, since it 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, AAURP yielded a shorter delivery delay than that of PROPHET by 230%, S&F by 50%, and SARP by 22%. AAURP can achieve a higher delivery ratio than DF by 73%, PROPHET by 79%, S&F by 66%, and SARP by 17%. Although SUARP produced more transmissions than MMF and DF, it yielded a smaller delivery delay than that of MMF by 82%, and DF by 66%. As the buffer size increased, the functioning of all protocols improved particularly for MMF and SARP. When the buffer size is larger than the traffic demand, the SARP scheme has yielded a competitive functioning due to the relaxation of buffer capacity restriction. AAURP still yielded the best functioning with a smaller number of transmissions than S&F by 33%.

The Effect of Traffic Load

The main goal of this premise is to observe the functioning impact and how AAURP 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 congested environment. We have two scenarios for nodal buffer capacity:

1) unrestricted capacity; and 2) low capacity (15 messages). Figure 7 shows thefunctioning of all the routing algorithms in terms of the average delivery delay, delivery ratio, and total number of transmissions.

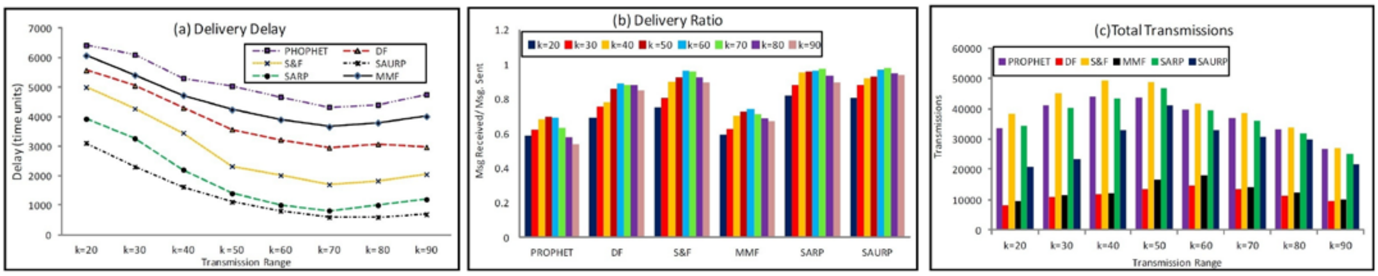
It is noticed that PROPHET produced the largest delivery delay and requires a higher number of transmissions compared to all the other schemes, thus it is not included in figure 7(c). PROPHET produced an order of magnitude more transmissions than that by AAURP.

As shown in Fig. 7(a), 7(b), and 7(c), when the traffic load is increased, the available bandwidth is decreased accordingly, which causes functioning reduction. When the traffic load is moderate (i.e., less that 50 messages), it is clear that the delivery delay is short in all the schemes, while AAURP outstrips 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 unrestricted number of messages while roaming among communities. AAURP can produce delay shorter than that of PROPHET, MMF, DF, S&F, and SARP by 350%, 52%, 400%, 250%, and 57%, respectively. Regarding the delivery ratio, AAURP, MMF, S&F, and SARP can achieve excellent functioning of 98%, while the PROPHET routing degrades below 60% for high traffic loads. DF can achieve delivery ratio above 92%.

As anticipated, the functioning of all the strategies degrades as wireless channel disputation is getting higher, particularly when the traffic load exceeds 50 messages per node during the simulation period. We noticed that AAURP can achieve substantially better functioning compared to all the other schemes, due to the consideration of busy links in its message forwarding mechanism, where the

Fig. 9. The effect of traffic load under high link bandwidth.

Fig. 10. The effect of connectivity.



corresponding routing metric is reduced accordingly. This results in the power 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 tranmissions than that of MMF and DF. In summary, the delivery delay found by the AAURP in this premise is shorter than that of PROPHET by 330%, MMF by 66%, S&F by 88%, DF by 233%, and SARP by 30% respectively. Regarding delivery ratio, AAURP can achieve as high as 93%, compared with 90 % by SARP, 87% by MMF, 77% by DF, and 88% by S&F. Even though DF produced the lowest number of transmissions, it is at the expense of the worst delivery delay.

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 functioning of all protocols degraded, particularly for the PROPHET and MMF. It is noticed that PROPHET produced the largest delivery delay. It is notable that AAURP outstrips 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, AAURP yielded shorter delivery delay than that of SARP by 28%, MMF by 53%, SF by 41%, DF by 47%, and PROPHET by 233%. Although AAURP requires more transmissions compared to the MMF and DF, the number is still smaller than that produced by S&F. AAURP can achieve delivery ratio above 76% for high traffic loads, while the SARP, PROPHET , DF, S&F, and MMF degrades by 66%, 47%, 51%, 62%, and 55%, respectively. Figure 8(a), 8(b), and 8(c) shows the functioning of all techniques under this scenario.

The Effect of Channel Bandwidth and Traffic Load

To examine the effect of channel bandwidth, the network connectivity is set to moderate (under moderate transmission range by setting K = 50), and the link capacity is set five times higher than that used in the previous scenarios in order to avoid bottlenecks in the traffic loads. Figure 9 shows the functioning of all the routing protocols in terms of the average delivery delay, delivery ratio, and total number of transmissions.

As the link bandwidth increased, it can be seen from Fig. 9 that the functioning of all routing strategies has improved with respect to delivery delay and delivery ratio, because the buffer capacity is unrestricted and the disputation on the bandwidth is relaxed. SARP achieved the best performance, while AAURP achieves the second best compared to the other schemes. It outstrips MMF scheme, since MMF is coupled by the number of message copies. Compared to PROPHET, DF, and S&F, AAURP has a shorter delay by 450%, 390%, and 83%, respectively. Meanwhile, AAURP needed much less transmissions compared to that by S&F. Even though DF produced the lowest number of transmissions, it has the worst functioning in terms of delivery delay and delivery ratio. All protocols achieved a delivery ratio above 90%. Compared to other protocols, AAURP asserts the second highest delivery ratio after SARP: above 96%.

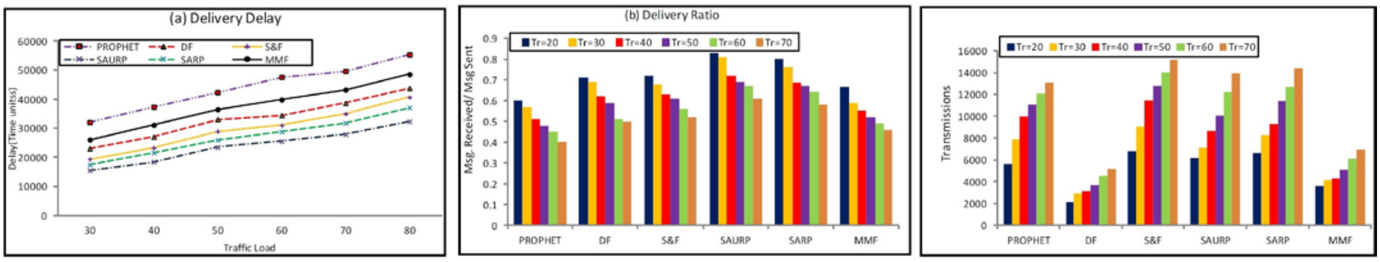
The above results show that channel bandwidth has substantial impact on the functioning of the protocols. If the available bandwidth is much higher than the total traffic load, flooding based strategies [15] can yield delivery delay as AAURP at the expense of taking far more transmissions. On the other hand, if the channel bandwidth is limited, AAURP and the spraying strategies outperform the flooding based strategies because of the disputation caused by restricted bandwidth.

The Effect of Connectivity

This premise studies the functioning impact due to network topology connectivity. In the scenario, the level of connectivity is increased from very sparse to highly associate by varying the value of K while observing the resultant impact on the performance. We are particularly interested to enquire the AAURP mechanism in response to heavy traffic loads which result in high disputation on the wireless channel. The buffer capacity is kept low (15 messages), and the traffic load is conceivably high (60 messages per node). Figure 10 shows the average delay, delivery ratio, and the number of transmissions as a function of transmission range.

Fig. 11. The effect of traffic load under trace based scenario.

AAURP outstrips all the strategies in terms of delivery delay while taking noticeably fewer transmissions than that by S & F and SARP strategies under all connectivity conceived in the simulation. When the network is sparsely associated, AAURP can achieve shorter delivery delay than all other strategies that is because the functioning of other strategies is affected by the uncertainty of buffer occupancy status. On the other hand, when the network is moderate associated, SARP can achieve commutative level of delivery



delay compared to AAURP with more transmissions. As the network becomes almost associated and the traffic load is high, the uncertainty of both buffer occupancy status and the availability of bandwidth affect the functioning of the other techniques. As a result, AAURP outstrips all other strategies in terms of delivery delay and delivery ratio.

5.3 Real Trace Scenario

In order to evaluate AAURP in realistic environment, the functioning of the scheme is examined using real encounter traces. These data sets comprise of contact traces between short ranges Bluetooth enabled devices carried by individuals in Infocome 2006 conference environment. More details about the devices and the data sets, including synchronization issues can be found in [43]. In order to observe the functioning impact and how AAURP reacts under congested environment, we set the bandwidth, buffer capacity, and the distribution of the contact time such that congested surroundings is formed. The channel bandwidth is set relatively quite small (i.e., one message transfer per unit of time), and the buffer size is set to 10, under different levels of traffic demand.

Figure 11 shows the functioning of all the routing algorithms in terms of the average delivery delay, delivery ratio, and total number of transmissions.

As the buffer capacity is low and the traffic load is high, the available bandwidth decreases and the buffer occupancy increases accordingly, which makes the functioning of all protocols degraded, particularly for the PROPHET and MMF. It is noticed that PROPHET produced the largest delivery delay. It is field to at least 2.1 times of longer delivery delay than that by SARP. It is notable that AAURP outstrips 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, AAURP yielded shorter delivery delay than that of MMF by 52%, SF by 30%, and DF by 40%. Although AAURP requires more transmissions compared to the MMF and DF, the number is still smaller than that produced by S&F. AAURP can achieve delivery ratio above 76% for high traffic loads, while the SARP, POPHET, DF, S&F, and MMF degrades by 67%, 38%, 53%, 60%, and 50%, respectively.

6 Conclusion

The paper acquainted a modern multi-copy routing scheme, called AAURP, for sporadically associated mobile networks that are possibly formed by densely distributed and hand-held devices such as smart phones and personal digital assistants. AAURP 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 modern contact model, where the network status, including wireless link status and nodal buffer availability, are jointly conceived. We provided an analytical model for AAURP, whose correctness was further affirmed via simulation. We further compared AAURP with a number of counterparts via wide simulations. It was shown that AAURP can achieve shorter delivery delays than all the existing spraying and flooding based strategies when the network experiences conceivable disputation on wireless links and/or buffer space. The study provides significance that when nodal contact does not solely serve as the major functioning element, the DRN routing functioning can be substantially improved by further conceiving other resource restrictions in the utility function and message weighting/forwarding process.

References

[1] ConcluY.-S. Chen, S.-Y. Ni, Y.-C. Tseng, and J.-P. Sheu. “The broadcast storm problem in a mobile ad hoc network”. Wireless Networks, 8(2/3), 2002.

[2] D. Becker and A. Vahdat, “Epidemic Routing for Partially Connected Ad Hoc Networks ,” Duke University, Tech. Rep. CS-2000-06, July.

[3] K. Psounis, T. Spyropoulos, and C. S. Raghavendra. “Efficient Routing in Intermittently Connected Mobile Networks: The Single-copy Case,” IEEE Trans. Networking Vol. 16, Issue. 1, Feb. 2008.

[4] A. Doria, A. Lindgren, and O. Schelen. Probabilistic routing in intermittently connected networks. SIGMOBILE Mobile Comput. Commun. Rev., 7(3):19–20, 2003.

[5] Disruption Resistant Networking. http://www.dtnrg.org.

[6] K. Psounis, T. Spyropoulos, and C. S. Raghavendra. “Performance analysis of mobility-assisted routing,” in Proc. ACM/IEEE MOBIHOC, 2006.

[7] M. Grossglauser, H. Dubois-Ferriere, and M. Vetterli. Age matters: efficient route discovery in mobile ad hoc networks using encounter ages. In Proceedings of ACM/IEEE MOBIHOC, pages 257–266, 2003.

[8] Haiying Shen and Z. Li. Utility-based Distributed Routing in Intermittently Connected Networks. 37th International Conference on Parallel Processing. (ICPP ’08). September 8-12, 2008, Portland, Oregon, USA.

[9] Z. Zhang. Routing in Intermittently Connected Mobile Ad Hoc Networks and Delay Tolerant Networks: Overview and Challenges. IEEE Communications Surveys and Tutorials, 8(1).

[10] Konstantinos Psounis, Thrasyvoulos Spyropoulos, and Cauligi Raghavendra, “Efficient routing in intermittently connected mobile networks: The Multi-copy case,” IEEE Trans. Networking vol. 16, Issue 1, Feb. 2008.

[11] Pin-Han Ho and Ahmed Elwhishi. 2009. SARP - a novel multi-copy routing protocol for intermittently connected mobile networks. In Proceedings of the 28th IEEE conference on Global telecommunications (GLOBECOM'09), Mehmet Ulema (Ed.). IEEE Press, Piscataway, NJ, USA, 4482-4488.

[12] D. A. Maltz, J. Broch, D. B. Johnson, Y.-C. Hu, and J. Jetcheva. A performance comparison of multi-hop wireless ad hoc network routing protocols. Proc. ACM MobiCom. Oct. 1998 .

[13] M. Crovella, V. Erramilli, A. Chaintreau , C. Diot. Delegation forwarding. Proceedings of the 9th ACM international symposium on Mobile ad hoc networking and computing, May 26-30, 2008, Hong Kong, Hong Kong, China.

[14] K. Psounis, T. Spyropoulos, and C. S. Raghavendra. “Utility-based Message Replication for Intermittently Connected Heterogeneous Wireless Networks”, in Proceedings of IEEE WoWMoM workshop on Autonomic and Opportunistic Communications (AOC), (INRIA Technical Report RR-6129), June 2007.

[15] S. Hailes, M. Musolesi, and C. Mascolo. Adaptive routing for intermittently connected mobile ad hoc networks. In Proceedings of IEEE WoWMoM, June 2005, pp. 183–189.

[16] Mascolo C. and Musolesi M., 2009. CAR: Context-aware Adaptive Routing for Delay Tolerant Mobile Networks. IEEE Transactions on Mobile Computing. 8, 2 (February 2009), 246-260.

[17] Jean-Yves Le Boudec, M. V. Thomas Karagiannis, “Power law and exponential decay of inter contact times between mobile devices,” in Proc. of ACM/IEEE MobiCom, 2007.

[18] K. Naik, A. Elwhishi Pin-Han Ho, and B. Shihadda. ARBR: Adaptive Reinforcement-Based Routing for DTN. WiMob 2010. Oct. 11-14: 376-385.

[19] K. Psounis, T. Spyropoulos, and C. Raghavendra. 2005. Spray and wait: an efficient routing scheme for intermittently connected mobile networks. In Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking (WDTN '05).

[20] Lily Li, Evan P. C. Jones, and Paul A. S. Ward. Practical Routing in Delay-Tolerant Networks.In SIGCOMM'05 Workshops, August 22–26, 2005, Philadelphia, PA, USA.

[21] V. Erramilli, M. Crovella. Forwarding in opportunistic Networks with Resource constraints. CHANTS'08, September 15, 2008, San Francisco, California, USA.

[22] Wu Wei, Shen Ling. "Feedback Adaptive Routing Algorithm for DTN," cmc, vol. 2, pp.267-271, 2009 WRI International Conference on Communications and Mobile Computing, 2009.

[23] B. Levine, A. Balasubramanian, A. Venkataramani, DTN routing as a resource allocation problem, Proceedings of the 2007 conference on Applications, technologies, architectures, and protocols for computer communications, August 27-31, 2007, Kyoto, Japan.

[24] T. Turletti, T. Spyropoulos, and K. Obraczka, “Routing in delay-tolerant networks comprising heterogeneous node populations,” IEEE Transactions on Mobile Computing, vol. 8, no. 8, pp. 1132–1147, August 2009.

[25] Cardei, Q. Yuan, and J. Wu. 2009. Predict and relay: an efficient routing in disruption-tolerant networks. In Proceedings of the tenth ACM international symposium on Mobile ad hoc networking and computing (MobiHoc '09).

[26] Mehedi Bakht, Samuel C Nelson, Robin Kravets, and Albert F. Harris, III. 2009. Encounter: based routing in DTNs. SIGMOBILE Mob. Comput. Commun. Rev. 13, 1 (June 2009), 56-59.

[27] Psounis And A. Jindal. Contention-aware performance analysis of mobility-assisted routing. IEEE Transactions on Mobile Computing, February 2009.

[28] “DTN java simulator,” http://people.ee.ethz.ch /spyropot /dtnsim.html.

[29] P. Nain, R. Groenevelt, and G. Koole. The message delay in mobile ad hoc networks. In Performance, October 2005.

[30] Akkouchi M. On the convolution of exponential distributions. J. Chungcheong Math. Soc, vol. 21 no.4. pp.501–510, 2008.

[31] Crowcroft, P. Hui, and E. Yoneki, “Bubble rap: Social-based forwarding in delay tolerant networks,” in MobiHoc '08: Proceedings of the 9th ACM international symposium on Mobile ad hoc networking & computing, May 2008.

[32] Haahr M. and Daly E. M., "Social Network Analysis for Information Flow in Disconnected Delay-Tolerant MANETs," Mobile Computing, IEEE Transactions on , vol.8, no.5, pp.606-621, May 2009 doi: 10.1109/TMC.2008.161 .

[33] Naik, T. Abdelkader, A. Nayak, and N. Goel, "A Socially-Based Routing Protocol for Delay Tolerant Networks", in Proc. GLOBECOM, 2010, pp.1-5.

[34] Haahr M. and Daly E. M., Social Network Analysis for Routing in Disconnected Delay-Tolerant MANETs. MobiHoc'07, ACM 978-1-59593-684-4/07/0009, September 2007.

[35] Shlomo Berkovsky, Jill Freyne, Elizabeth M. Daly, and Werner Geyer. 2010. Social networking feeds: recommending items of interest. In Proceedings of the fourth ACM conference on Recommender systems (RecSys '10). ACM, New York, NY, USA, 277-280.

[36] B. Gallagher, J. Burgess, D. Jensen, and B. N. Levine, “MaxProp: Routing for vehicle-based disruption-tolerant networks,” in Proc. of INFOCOM, 2006.

[37] Yong Liao, el at, cooperative robust forwarding scheme in DTNs using erasure coding, MILCOM 2007.

[38] Q. Zhang, K. Tan, and W. Zhu, “Shortest path routing in partially connected ad hoc networks,” in Globecom, 2003.

[39] J. Wu and F. Li, “Mops: Providing content-based service in disruptiontolerant networks,” in Proc. of ICDCS, 2009, pp. 526–533.SimBet: E. M. Daly and M. Haahr, “Social network analysis for routing in disconnected delay-tolerant manets,” in Proc. of MobiHoc, 2007.

[40] Y. Yi, K. Lee, J. Jeong, H. Won, I. Rhee, and S. Chong, “Max-Contribution: On optimal resource allocation in delay tolerant networks.” in Proc. of INFOCOM, 2010.

[41] C. Barakat, A. Krifa, and T. Spyropoulos. Optimal buffer management policies for delay tolerant networks. In Proc. of IEEE SECON, 2008.

[42] C. Marco, B. Chiara, J. Jacopo, and P. Andrea, “Hibop: A history based routing protocol for opportunistic networks,” in Proc. of WoWMoM2007, 2007, pp. 1–12.

[43] HUI P.,CHAINTREAU A., CROWCROFT J., DIOT C., GASS R., AND SCOTT J., Impact of Human Mobility on Opportunistic Forwarding Algorithms. IEEE Trans. on Mobile Computing 6, 6 (2007), 606–620.