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Performance Comparison of Routing Protocols in Opportunistic Networks

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ABSTRACT

In Opportunistic Networks (OppNets), mobile devices transmit messages by exploiting the direct contacts, without the need of an end-to-end infrastructure. Disconnections of nodes and high churn rates are normal features of opportunistic networks. Hence, routing is one of the main challenges in this environment. In this paper, we provide a survey of the main routing approaches in OppNets and classify them into two classes: context-oblivious and context-based routing. We emphasize the role of context information in forwarding data in OppNets, and evaluate the relative performance of Epidemic and PROPHET routing protocols.

Keywords: *opportunistic networks, context information, context-aware routing, delay-tolerant networks.*

1. INTRODUCTION

The elimination of the need to build paths drastically simplifies the routing in opportunistic networks; however, challenges remain that are distinct from those of conventional network routing methods. A routing scheme in OppNets has to provide data with some reliability even when the network connectivity is intermittent or when an end-to -end path is temporally nonexistent. Moreover, since “contacts” in an opportunistic network may appear arbitrarily without prior information, neither scheduling routing nor mobile relay approaches can be applied. In such environments, flooding-based routing protocols appeared for some time to be popular design choice. However, this approach tends to be very costly in terms of traffic overhead and energy consumption. Routing performance improves when knowledge regarding the expected topology, the behavior of the participants, and the information about the participants themselves in the networks can be exploited: that is, the context information of the networks.

Context information can cover various ranges, depending on the specific routing protocols. It could be the workplace, home address, profession, and email address, the mobility pattern of nodes, or the communities that the nodes belong to, and so on. All information that aids in making decisions to route messages is context information. For example, to identify those hops best suited for communication towards the eventual destination, the home address of a user is a valuable piece of context information. In the following section, we provide a brief description of the primary routing approaches in OppNets available in the literature, from “naïve” approaches to “intelligent” ones. Specifically, we emphasize the role of context information as well as social aspects in routing messages, where the classification of routing approaches is based on the amount of context information used as given in [1]. Based on the context information exploited we classify routing in OppNets into two classes: context-oblivious, context-based routing protocols.

2. CONTEXT-OBLIVIOUS ROUTING

Flooding-based routing algorithms belong to the context-oblivious routing group, from “blindly” flooding techniques to controlled flooding solutions. In flooding techniques, a source node sends out a request packet on its entire outgoing links. Each node receives a request packet and forwards the packet on its entire outgoing links except the one corresponding to the incoming link on which the packet arrives. Each request packet may reach the destination node along a different route at a different time. The advantage of flooding-based routing is its simplicity in finding a route, in particular, a minimum delay ratio for a connection request because it doesn’t require any global information about network topology, or any context information. However, flooding causes a huge number of control packets in control channels, which can result in network congestion. Moreover, this kind of technique floods all the nodes in the network, and is thus very costly in terms of energy consumption and memory. Network performance is particularly important in OppNets because of the device constraints. One way to address this problem is to use a hop counter in the header of each packet and decrement it at each hop; when the counter of a packet reaches zero, the packet is discarded. Another approach is to set Time-To-Live (TTL) for each packet as in Epidemic routing [2]. Epidemic routing customizes traditional flooding to mobile opportunistic networks. It is one of the first schemes proposed to enable message delivery in such networks. Each node maintains a list of all messages it carries, whose delivery is pending. Whenever it encounters another node, the two nodes exchange all messages that they do not have in common, and in this way, all messages are eventually spread to all nodes. The packet is delivered when the first node carrying a copy of the packet meets the destination. The packet will keep on getting copied from one node to the other node till its *TTL* expires.

Network coding based routing schemes for OppNets can also be classified as flooding based techniques. In network coding based routing schemes, a message (or group of messages) is transformed into another format prior to transmission [3, 4]. The design principle of coding based schemes is to embed additional information within the coded blocks such that the original message can be successfully re-constructed with only a certain number of the coded blocks. More precisely, differing from replication based schemes which rely on successful delivery of each individual data block; coding based schemes consider a block successfully delivered when the necessary number of blocks is received to reconstruct the original data, which can be just a small portion of the total number of the blocks transmitted. As a result, coding based schemes tend to be more robust than replication based schemes when network connectivity is extremely poor (this is considered as the worst delay performance case). However, coding based schemes are less efficient when the network is well connected (this is considered as the very small delay performance case), which is simply due to additional information embedded in the code blocks.

Another approach to route packets in sparse networks is that of controlled replication or spraying – Spray and Wait [5]. A small, fixed number of copies are distributed to a number of distinct relays. Then, each relay carries its copy until it encounters the destination or until the *TTL* of the packet expires. By having multiple relays looking independently and in parallel for the destination, this protocol creates enough diversity to explore the sparse network more efficiently while keeping the resource usage per message low. Spray and wait is one of the simplest spraying schemes proposed in the literature. Specifically, the source node forwards all the copies (let the number of copies being sprayed be labeled as L) to the first L distinct nodes it encounters. (In other words, no other node except the source node can forward a copy of the packet.) And, once these copies are distributed, each copy performs direct transmission. The analytical model derived in [5] shows that L can be chosen based on a target average delay. The spray phase may be performed in many ways. Under the assumption that nodes movements are independent and identically distributed, the Binary Spray and Wait policy is the best in terms of delay. Any node (including the sender) holding n copies ($n > 1$) of the message hands over ($n/2$) copies to the first encountered node, and keeps the remaining copies for itself. When a node is left with only one copy of the message, it switches to direct transmission and only transmits the message to the final destination node when (and if) it is met.

3. CONTEXT-BASED ROUTING

Routing protocols that lie in the mobility-based category exploit more context information to make forwarding decisions, such as the mobility information of nodes. Node mobility impacts the effectiveness of routing in Opportunistic Networks, and [6] proved that it increases the performance of ad hoc networks, especially in the routing of messages when efficient routing techniques are deployed. When network mobility departs from the well-known random way-point mobility model, [7] and [8] have shown that the overhead carried by epidemic and/or flooding based routing schemes can be further reduced by taking into account the knowledge of node mobility. The Probabilistic Routing scheme - PRoPHET [9] calculates the delivery predictability from a node to a particular destination node based on the observed contact history, and forwards a message to its neighboring node if and only if that neighbor node has a higher delivery predictability value. PRoPHET uses “History of past Encounters and Transitivity” to estimate each node’s delivery probability for each other node. The delivery predictability is the probability of a node encountering a certain destination. It increases when the node frequently meets the destination and decreases (according to an aging function) in the contrary.

The context information used in PRoPHET is the frequency of meetings between nodes, as is also seen in the MV (Meeting and Visits) and MaxProp protocols [10, 11]. A node uses MaxProp to schedule packet transmission to its peers and determines which packets should be deleted when buffer space is almost full. Packets are scheduled based on path likelihoods to peers according to historical data. In addition, several complementary mechanisms, including acknowledgments, a head-start for new packets, and lists of previous intermediaries are used in this approach. The MV routing protocol [10] also takes into account the frequency of meetings between nodes. The nodes remember their path (visits) and the other nodes they met on the way. Each node stores variables for all the nodes so far encountered, describing the likelihood of a successfully delivery to this node. When node A and B meet directly, they set the delivery probability to each other to 1, and synchronize their set of variables. These delivery probabilities degrade in time and are refreshed periodically by meeting with nodes with high delivery probability. If A meets B again, they synchronize again and reset the delivery probability between them to 1. However, the MV protocol introduces a more sophisticated method to select the messages to forward to an encountered node. Basically, the choice depends on the probability of encountered nodes to successfully deliver messages to their eventual destinations. The delivery probability relies on recent-past observations of both the meetings between nodes and the visits of nodes to geographical locations.

This scheme has been revised by [12] - MobySpace by taking the mobility pattern into account. In MobySpace, the mobility pattern is the context information that the source node uses to route the message. It relies on the notion that a node is a good candidate for taking a message if it has a mobility pattern similar to that of the destination. Routing is done by forwarding messages toward nodes that have mobility patterns that are more and more similar to the mobility pattern of the destination. To deal with the mobility patterns of node, a virtual Euclidean space is used where each axis represents a possible contact between a couple of nodes and the distance along an axis measures the probability of that contact to occur.

[13] propose routing based on the predefined infrastructure, such as the places that device holders often visited; they call them "solar-hub". This takes the advantage of user mobility profiles to perform "hub-level"-based routing. With "solar- hub", the message from the sender to the receiver is routed to one or more hubs frequently visited by the receiver, called destination hubs, where the receiver can retrieve the message when it visits the same hubs again. In this scenario, it is necessary to know about the places visited by the receiver (hubs).

Unlike Spray and Wait [5], in the second phase (“focus” phase) in Spray and Focus [14] rather than waiting for the destination to be encountered, each relay can forward its copy to a potentially more appropriate relay, using a carefully designed utility-based scheme. The potential relays are selected based on a set of timers that record the time since two nodes last saw each other. This last encounter timer criterion is also present in [15]. Here, node mobility is exploited to disseminate destination location information. Each node maintains a local database of the time and location of its last encounter with every other node in the network. This database is consulted by packets to obtain estimates of their destination’s current location. As a packet travels towards its destination, it is able to successively refine an estimate of the destination’s precise location, because node mobility has “diffused” estimates of that location.

The context information in Bubble Rap [16] is the social communities that nodes belong to. Communities are automatically defined and labeled based on the patterns of contacts between nodes. When a node wants to send a message to other node it looks for nodes belonging to the same community of the destination. If such nodes are not found, it forwards the message to increasingly sociable nodes, which have more chance of getting in touch with the community of the destination. The sociable level of a node is defined by the set of peers that the node is usually in touch with. Exploiting context information related to the social behavior of people is one of the most promising research directions in the area.

CAR-Adaptive Routing for Intermittently Connected Mobile Ad hoc Networks [17] uses Kalman filters to combine and evaluate the multiple dimensions of the context in order to take routing decisions. The context is made of measurements that nodes perform periodically, which can be related to connectivity, but not necessarily. The connectivity happens inside MANET clouds, to reach nodes outside the cloud; a sender looks for the node in its cloud with the highest probability of successfully delivering the message to the destination. Then this node temporarily stores the message, waiting either to get in touch with the destination itself, or to enter a cloud with other nodes with higher probability of meeting the destination. Therefore, nodes in context-aware routing compute delivery probabilities proactively, and disseminate them in their ad hoc cloud. Note that context information is exploited to evaluate probabilities just for the destinations that each node is aware of (i.e. that happen to have been co-located in the same cloud at some time). The main focus of context-aware routing is on defining algorithms to combine context information (which is assumed to be available in some way) to compute delivery probabilities. Specifically, a multi-attribute utility-based framework is defined in CAR. The framework is general enough to accommodate different types of context information. Context information in CAR consists of the logical connectivity of nodes, such as the rate of connectivity change, the delivery probability of the neighbor nodes to the destination, and device information, such as residual battery life. However, the social context information is not taken into consideration as in social context-based category (described in the next section). Thus, from this point of view, CAR can be seen as a conjunction between mobility-based protocols and social context-based protocols.

4. PERFORMANCE EVALUATION

4.1 Simulation Setup

We have currently implemented two different routing protocols Epidemic and PROPHET routing protocols in ONE (Opportunistic Network Environment) Simulator, all of which we consider in our evaluation. We are taking simulation scenario from [18], therefore we are not describing all things here. We are just showing here some important and new parameters.

We have used part of the Helsinki downtown area (4500×3400 m) as depicted in [18]. For our simulations, we assume communication between modern mobile phones or similar devices. Devices has up to 20 MB of free RAM for buffering messages. Users travel on foot, in cars or trams. In addition, we have added to the map data some paths to parks, shopping malls and tram routes. We run our simulations with 100 nodes. Mobile nodes have different speed and pause time. Pedestrians move at random speeds of 0.5–1.5 m/s with pause times of 0–120 s. Cars are optional and, if present, make up 20% of the node count; they move at speeds of 10–50 km/h, pausing for 0–120 s. 0, 2, 4, or 6 trams run as speeds of 7–10 m/s and pause at each configured stop for 10–30 s. We assume Bluetooth (10 m range, 2 Mbit/s) and a low power use of 802.11b WLAN (30 m range, 4.5 Mbit/s). Mobile users (not the trams or throw-boxes) generate messages on average once per hour per node. We use message lifetimes of 3, 6, and 12 hours. We use message sizes uniformly distributed between 100 KB (text message) and 2 MB (digital photo).

Additionally, we define two scenarios POIs1 and POIs2 using different POIs each contains five groups and creates four POI groups (west containing 3, central 4, shops 22, and parks 11 POIs) [18]:

- POIs1: One node group runs MBM (map-based model), three choose their next destination with a probability p = 0.1 for each of the four POI groups, the last remaining one only chooses from the POI groups that are accessible by car otherwise a random target is selected.

- POIs2: We consider a preferred POI group for four of the node groups. A node chooses a POI with p = 0.4 from its preferred POI group, with p = 0.1 from each other POI group, and otherwise a random target.

4.2 Performance Evaluation

Now we compare the performance PROPHET and Epidemic routing protocols in both scenarios when context information is present or not.

Figure 1 shows a comparison of message delay between PROPHET and Epidemic routing protocols in the presence of context information. It is noticed that PROPHET gives minimum message delay probability 0.2370. But in absence of context information it gives maximum message delay probability 0.2824 as it is noticed from Figure 2. Epidemic is totally flooding based routing protocol and does not require context information for message forwarding therefore it is not affected by unavailability of context information, and gives same message delay probability 0.2738 in both cases.

A comparison of message delivery probability between PROPHET and Epidemic protocols is shown in figure 3. It is noticed that the PROPHET gives better message delivery probability 0.2981 in the case of available context information, but on unavailability of context information it gives worst message delivery probability 0.1978 as it noticed from Figure 4. Epidemic does not use context information, therefore gives same delivery probability 0.2334 in both cases.

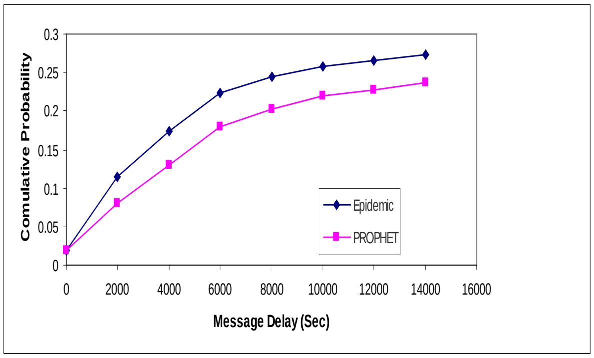

Figure 1. Comparison of Message Delay of routing protocols (Presence of context information).

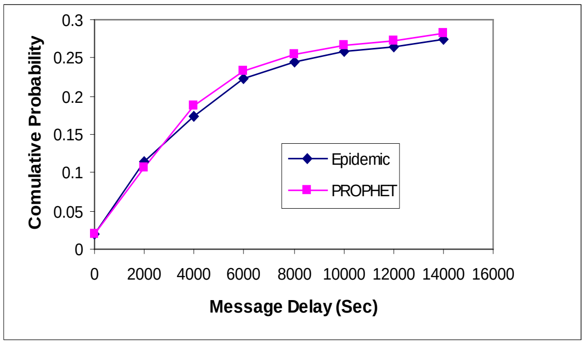

Figure 2. Comparison of Message Delay of routing protocols (Absence of context information).

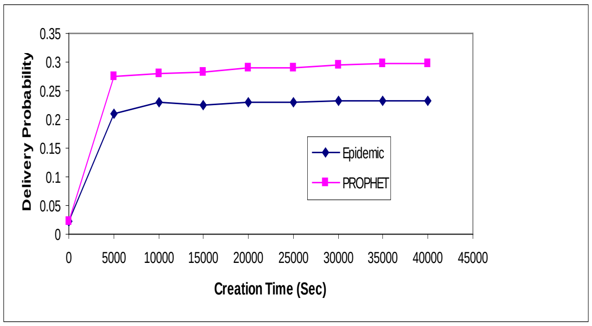

Figure 3. Comparison of Message Delivery Probability of routing protocols (Presence of context information).

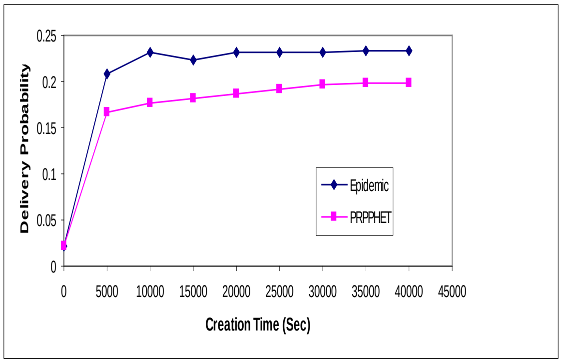

Figure 2. Comparison of Message Delivery Probability of routing protocols (Absence of context information).

Our simulation results show that PROPHET gives batter results in presence of context information. When users are very isolated, context information cannot be distributed, and cannot be used for taking effective routing decisions in this case Epidemic routing gives a better result more than PROPHET which gives worst result. Epidemic routing is not affected by unavailability of context information which gives the same results in both cases.

5. CONCLUSION

Opportunistic networking is a very promising technology for realizing the ubiquitous vision. Based on the increasing pervasiveness of our world, and on releasing end-to-end connectivity constraint, it can better exploit social characteristics via context awareness. We presented here a classification of routing schemes in OppNets based on the types of information they use and how this is handled.

Simulation results show that PROPHET routing protocol gives batter results in presence of context information. When users are very isolated, context information cannot be distributed, and cannot be used for taking effective routing decisions. In this case PROPHET gives worst results but Epidemic gives a better results than it which are same results in both cases when the context information is available or not.

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