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Energy-Aware Social-based Routing in Opportunistic Networks[1]

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Abstract — ***In particular types of Delay-Tolerant Networks (DTN) such as Opportunistic Mobile Networks, node connectivity is transient. For this reason, traditional routing mechanisms are no longer suitable. New approaches use social relations between mobile users as a criterion for the routing process. We argue that in such an approach, nodes with high social popularity may quickly deplete their energy resources – and, therefore, might be unwilling to participate in the routing process. We show that social-based routing algorithms such as BUBBLE Rap are prone to this behavior, and introduce energy awareness as an important criterion in the routing decision. We present experimental results showing that our approach delivers performances similar to BUBBLE Rap, whilst balancing the energy consumption between nodes in the network.***

Keywords: opportunistic networking, mobile devices, energy awareness.

1. Introduction

Energy consumption is a major factor in the performance and deployment of modern computational and communication systems. It is increasingly necessary to preserve scarce resources and have such systems perform with the utmost energy efficiency. In order to achieve as minimal energy consumption as possible while maintaining extreme adaptability to environmental challenges and resources it is necessary to develop highly autonomous systems with the capability to adapt dynamically to energy availability and usage.

The emergence and wide-spread of new-generation mobile devices together with the increased integration of wireless technologies such as Bluetooth and WiFi create the premises for new means of communication and interaction, challenge the traditional network architectures and are spawning an interest in alternative, ad-hoc networks such as opportunistic mobile networks. An opportunistic mobile network (ON) [7] is established in environments where human-carried mobile devices act as network nodes and are able to exchange data while in proximity. Whenever a destination is not directly accessible, a source would opportunistically forward data to its neighbours. The latter act as carriers and relay the data until the destination is reached or the messages expire. ONs do not rely on any kind of existing infrastructure, and commit solely to human mobility for data delivery. In this scenario, new challenges emerge: there is no a-priori known topology (as user mobility is highly unpredictable), end-to-end paths between communicating nodes may be absent [8] (for several reasons: uneven node distribution in the environment, *energy conserving policies*, etc.), the computing and memory resources available for each node are limited. Unlike conventional networks, where faults are considered exceptions, in ONs it is assumed they are common. Therefore, traditional routing mechanisms such as those from the TCP/IP stack are an unsuitable solution for ad-hoc networks such as ONs. The natural approach is to extend the store-and-forward routing to store-carry-forward (SCF) routing [9].

Routing algorithms for ONs are either mobility-aware or social-aware. The former (which includes protocols such as PRoPHET [10]) takes routing decisions based on the number and duration of node encounters; the latter (which includes BUBBLE Rap [1]) relies on the knowledge that members (or nodes) of an ON are people carrying mobile devices. ONs involve routing decisions based on how people are organized into communities, according to places of living and work, common interests, leisure activities, etc. In this case social relations between people can be generally inferred from the user interactions in such networks. This is why in recent years, researchers have started to show an interest in social-based routing algorithms for ONs. However, approaches such as [1] can quickly deplete the energy of more popular ON

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members, which can become flooded by message forwarding requests.

In this paper we present a novel social-driven solution which includes energy as an important element in selecting the routing decision. If energy consumption is considered, in social-driven ON routing popular nodes can be cumbered and their resources drained. This may cause popular nodes to become unavailable and the benefits they bring to the network disappear. Such a scenario is unlikely in an environment where recharging points for the battery are widely available, especially with improvements in battery life, but in case of natural disasters or areas that do not benefit of the abundance of charging points, or when energy is scarce, extending the energy life of the network quickly becomes important priority.

The rest of the paper is structured as follows: Section 2 presents related work. In Section 3 we describe the proposed energy-aware routing algorithm. Section 4 presents simulation results and comparisons with other algorithms, and finally in Section 5 we conclude and suggest future work.

2. Related Work

Since opportunistic networks have become more and more popular over the past years, partly due to the ubiquitousness of mobile devices, several authors have treated this research area in great detail. A review of opportunistic networking can be found in [11], where functions such as message forwarding, security, data dissemination and mobility models are analyzed. Several opportunistic forwarding algorithms are also reviewed, among them being BUBBLE Rap [1], and PROPICMAN [12]. We previously proposed a taxonomy for data dissemination algorithms in [13], where we split such algorithms into four main categories. The first category refers to the infrastructure of the network, i.e. the way the network is organized into an overlay. The dissemination techniques are also split according to their node properties, such as state or interaction. The third category of the taxonomy is represented by content characteristics, i.e. the way content is organized and analyzed, and finally the last category (and the most important one, in our opinion) is social awareness. We consider it to be the future of opportunistic networks, because the nodes in such a network are mobile devices carried by humans, which interact with each other according to social relationships. The addition of social network information to opportunistic routing has been studied in [15], where the authors show that using Facebook information instead of community detection algorithms decreases the delivery cost and produces comparable delivery ratio. Still

BUBBLE Rap [1] is a social based forwarding algorithm for use in delay tolerant networks. In BUBBLE Rap, a message is forwarded to the most popular node in the local community of the current node (bubbled up) by using the local rank, and sent between different communities by means of a global rank. Once the node with the greatest local rank has been reached, the routing continues at a global level (between different communities in the opportunistic network) until a community of a destination is reached. Then the message is locally forwarded until it reaches the destination node. BUBBLE Rap shows significant improvements when compared to non-social routing algorithms applied on Opportunistic Networks.

There are a number of successful attempts of improving the performance of the BUBBLE Rap algorithm [1]. Socially-Aware Prediction (SAP) [4] is an algorithm created for opportunistic routing which forwards a message to a node that has a high probability of establishing a connection with the destination node. The algorithm accomplishes this by considering how recent the message is, the community to which the node belongs, the social distance between the source and the destination of the message, the number of hops the message has passed through, "the total time spent by the next node in contact with the messages destination" ([4]) and the time of day when the next node frequently forms a connection with the destination.

Still, such social-aware routing protocols for ONs are energy-unaware. In contrast, protocols such as Biased Random Algorithm for Load Balancing (BRALB) [6], assume a static network, and forward messages to neighbors with which a node had the smallest number of message transfers. This is done to improve the overall energy use of the system by constantly modifying the transmission path. Still, to the best of our knowledge, the addition of an energy-aware layer over the routing decision in social-driver ONs was never tackled before.

Also, in our experiment we consider Epidemic [2] to be a interesting theoretical algorithm that offers good comparison metrics when dealing with Opportunistic Mobile Networks. Unfortunately, the way Epidemic works, by sending a message to all the neighboring nodes, presumes infinite storage capacity and infinite resources (such as battery, bandwidth, and processing power). As such Epidemic does not have a real world use and it should only be use in comparison with other algorithms.

3. Energy-Aware BUBBLE Rap

As explained, "Energy-Aware BUBBLE Rap" (or EA BUBBLE Rap) combines socially-aware routing with energy consumption optimization. The goal is to balance the energy consumption of the ON, making it uniform, whilst maintaining or even reducing the delivery cost and hop count. Thus, our objective is to increase the overall life of the network. In the original BUBBLE Rap algorithm, when two nodes meet they use a utility function to decide for each message to forward it through the neighboring node. The decision includes the global and local ranks of the two nodes that meet. If a node has a higher rank, the probability that it will receive more forward packages increases, since its centrality is higher.

In our approach, we extend the utility function to allow it to also decrease if the neighboring node has insufficient energy resources to support the message transfer. As the energy decreases, the probability for that node to be a successful carrier also decreases.

To make the routing decision energy aware, we introduce the cost of using particular resources (such as battery), with the following properties:

- $\frac{df(e)}{de} < 0$, which means that the utility function *f(e)*, decreases with the increase of the energy consumption - so a node will not accept messages in transit if the battery is depleted for example.
- $\frac{d^2 f(e)}{de^2} > 0$, which means that the utility function decreases rapidly, considering the concavity of this function (the routing decision must be able to quickly react to possible changes in energy conditions).
- $0 < f(e) \le K$, which means that we have a threshold for this utility function.

Here e is the energy level of a node. We also consider e_{max} a maximum energy level (in a realist world smartphones dispose of limited energy).

Under these assumption, the energy-aware routing process can be modelled similar to an evolutionary process, in an electrical RLC circuit (where active and passive components have important roles in the evolution of the process). Thus, we apply a similar method to describe the evolution of the utility function for a particular smartphone as:

$$\frac{d^2 f(e)}{de^2} + \frac{\alpha}{2}\frac{df(e)}{de} + \frac{\alpha^2}{2} f(e) = 0$$

The equation has as solution:

$$f(e) = K \exp\{-\alpha e\},$$

where K is a constant that will be set as a threshold for the utility function, and α is a quality factor for the utility function which depends on the maximum assumed energy (for a smartphone, or for a particular route). So, considering a control point for the utility function of $(e_{\max}, \varepsilon)$, which means that for the maximum level of energy we reach the $\varepsilon \cdot K$ threshold (a small fraction of the K threshold), we now have $\alpha = -\ln \varepsilon / e_{\max}$, thus:

$$f(e) = K \exp\{\ln \varepsilon \cdot e / e_{\max}\} \qquad (1)$$

The constant ε in our experiments was considered to be 10^{-3}, based on empirical observations, as a limit for practical measurements.

```
begin EABubbleProcedure ()
  if ( LabelOf ( currentNode ) == LabelOf ( destination ) ) then
    if ( LabelOf ( EncounteredNode_i ) == LabelOf ( destination ) )
      and ( NewLocalRankOf ( EncounteredNode_i ) >
     NewLocalRankOf ( currentNode ) )
    then
      EncounteredNode_i . addMessageToBuffer ( message )
  else
    if ( ( LabelOf ( EncounteredNode_i ) == LabelOf ( destination ) )
      or (NewGlobalRankOf ( EncounteredNode_i ) >
      NewGlobalRankOf (currentNode ) ) )
    then
      EncounteredNode_i . addMessageToBuffer (message )
end
```

Listing 1. The adjusted BUBBLE Rap procedure.

The logic implemented at the encounter of an arbitrary node from the ON is shown in Listing 1. Here *NewLocalRankOf* and *NewGlobalRankOf* are obtained as sum between the original local and global functions defined by BUBBLE Rap, and the energy-aware utility function shown in Eq. 1.

4. Experimental Setup and Results

This section represents an experimental analysis of the Energy-Aware BUBBLE Rap algorithm.

4.1. Experimental setup

To evaluation experiments were first performed on the UPB 2012 trace [5]. The trace includes 66 participants from the University POLITEHNICA of Bucharest. For 64 days the participants recorded their contacts on Bluetooth and Wi-Fi. We validated next our conclusions on another trace, from University of Cambridge, Cambridge-haggle-imote-content [3]. In this trace the data was collected with 36 mobile participants that used Intel iMote devices, small sensors that run ARM7 and can communicate throw Bluetooth, and 18 fixed ones, in an area of 3 km^2.

We assumed an energy model (i.e., battery life) where the energy decreases linear with the transmission of each message. Every time a message is exchanged between two nodes, one energy unit is consumed by each node (for send and receive). During the experiments we varied the amount of energy available for each device/node. All devices start with the same amount of energy. Also, the number of messages sent through the network is of 580 for UPB2012, and 1001 for Cambridge-haggle-imote-content (because of different densities in nodes and contacts between the two traces). We considered only the energy depletion process, and we assume that when a node reaches the bottom level energy it will not be able to participate anymore in the communication (i.e., a smartphone with no battery cannot forward anymore messages).

Finally, we compared our proposed algorithm with the original BUBBLE Rap, as well as with Epidemic, under the same conditions.

4.2. Experimental Results

There are several metrics that we use for analyzing the simulation data. First of all, we look at *hit rate*, which is the ratio between data objects that have successfully arrived at requesting nodes and the total number of requests generated by all nodes. Although in this paper we treat the energy problem, hit rate still remains the main goal of opportunistic routing algorithms. Achieving a hit rate close to 100% means that ONs are plausible for implementation in real-life. Secondly, we consider the *delivery cost* as the ratio between the total number of messages exchanged during the course of the experiment and the number of generated messages. This is a measure of network congestion, since fewer messages sent in the network leads to a less congested network. Another measure of congestion, but this time at the nodes, is the *hop count*. It is computed as the number of nodes that carried a message until it reached the destination on the shortest path.

Finally, for our experiments we looked at the *amount of energy consumed by each node* at the end of each round. Under different initial levels of energy existing in the network, we were interested how the routing decision balances the remaining energy of nodes.

Figure 1. UPB2012 - 5,000 Maximum Energy.

Figure 2. UPB2012 - 20,000 Maximum Energy.

Figure 3. UPB2012 - 10,000 Maximum Energy.

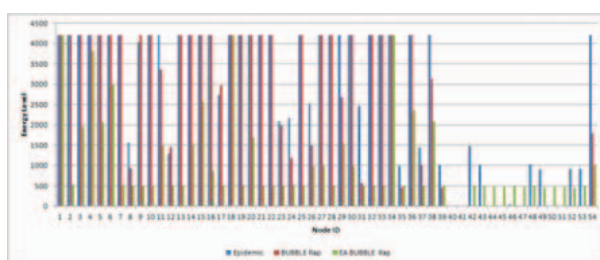

Figure 4. Cambridge-iMote - 4,200 Maximum Energy.

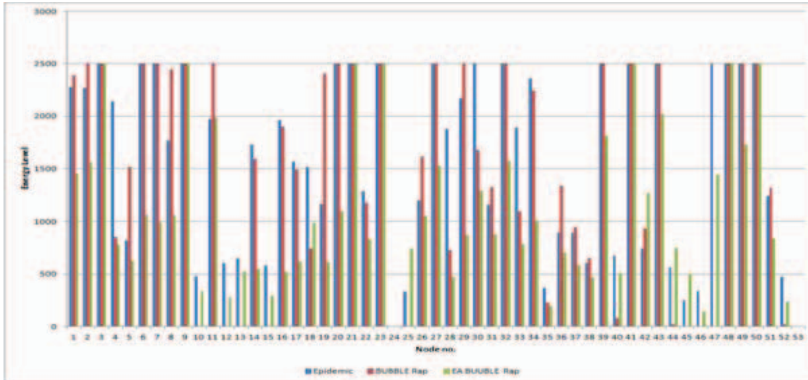

Figure 5. UPB2012 – 2,500 Maximum Energy.

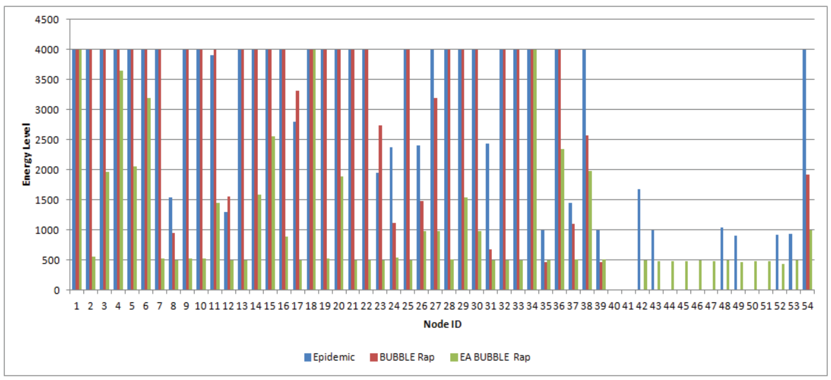

Figure 6. Cambridge-iMote - 4,000 Maximum Energy.

A well-balanced result show that nodes are still able to preserve their energy for possibly other critical local services (such as making a phone call) – and the overall life-time of the network is expanded. A non-balanced result show that some nodes lose their capability to participate in the communication (and, possibly, the energy for other services as well).

The results obtained for the energy consumption are presented in Figures 1-6. As seen, EA BUBBLE Rap manages to balance the energy consumption between more nodes inside the network. The algorithm manages to protect a higher number of devices from energy depletion. This also helps the network by decongesting the popular nodes, the ones that reach the maximum allowed consumed energy first. In a real life scenario other improvements may be noticed, like lowering the bandwidth use of the popular nodes.

In terms of *delivery cost*, by decongesting the popular nodes messages actually need fewer transfers or hops to get to the destination, thus lowering the delivery cost (see Figure 7). This can also be seen in the average hop count (see Figure 8).

The average hop count can vary because by avoiding the popular nodes most messages need to find a longer path to get to their destination. But depending on the stability of the network, avoiding the popular nodes can prove to be an advantage. The differences in the following metrics are better seen if the devices have a smaller energy life (Figure 8).

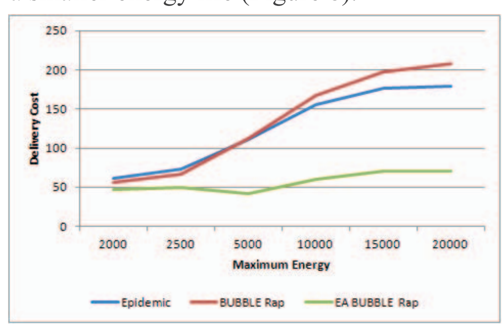

Figure 7. UPB2012 - Delivery Cost.

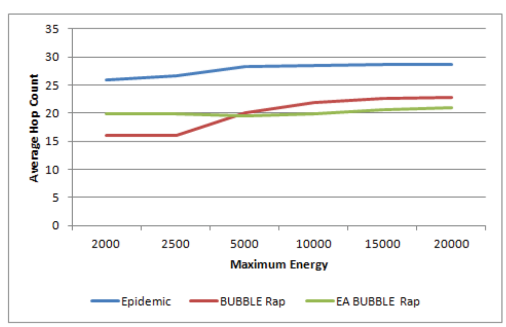

Figure 8. UPB2012 - Average Hop Count.

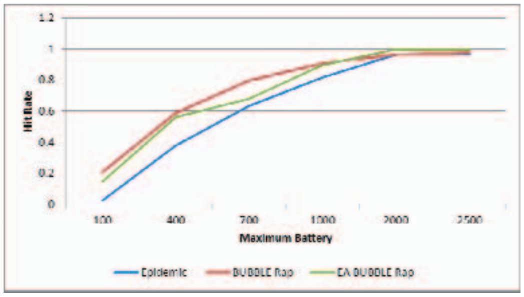

Figure 9. UPB2012 - Hit Rate.

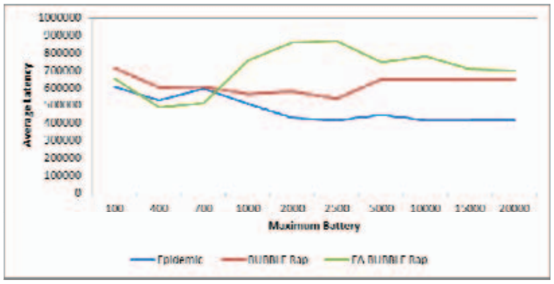

Figure10. UPB2012 - Average Latency.

In terms of *hit rate* (Figure 9), EA BUBBLE Rap manages to deliver a similar or larger amount of messages. In the case of bigger battery life it actually manages to reach 100% message delivery and it does this with less maximum battery than the other 2 algorithms.

Because of the way EA BUBBLE Rap avoids the popular nodes it takes a larger amount of time to deliver the messages (Figure 10). Still, in case of a small amount of available energy, the algorithm manages to deliver better results than the other two algorithms.

5. Conclusion

In this paper we presented a novel social-driven routing algorithm for ONs, which includes energy as an important element in selecting the routing decision. As demonstrated, when energy consumption is considered in social-driven ON routing, popular nodes can be saved from their resources being drained (we demonstrated such a behavior for social-based routing algorithms such as BUBBLE Rap). After introducing energy awareness as an important criterion in the routing decision, we presented experimental results showing that our approach delivers performances similar to BUBBLE Rap, whilst balancing the energy consumption between nodes in the network. The results demonstrate that the total life span of the ON is increased, with minor or no modifications of hit rate and significant improvements to delivery cost.

The work presented in this paper can bring significant advantages to DTNs, especially in scenarios where battery life is a key factor and recharging points are scarce.

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