Investigation of "Six Degrees of Separation" Conjecture of Small-World Networks to Improve Routing in Opportunistic Networks

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Abstract

The "six degrees of separation" conjecture of small-world networks indicates the degree of separation between two nodes in a graph. In this paper, we investigate the argument that each node is separated by, at most, six hops (six-degree conjecture) and propose a simple algorithm for routing in Opportunistic Networks. We carried out simulations with real world traces using ONE simulator and demonstrate that our approach outperforms some popular protocols. We conclude that static graph models are not suitable for underlay routing approaches in highly dynamic networks like Opportunistic Networks without taking account of temporal factors such as time, duration and frequency of previous encounters. Moreover, we signal the direction for further research towards the application of some statistical or machine learning method to predict internal configuration values of our routing algorithm using contextual or situational information of nodes.

1. Introduction

In everyday life, improvements of mobile devices with wireless technologies, such as IEEE 802.11, WiMAX, Bluetooth, and other short range radio solutions (sensor devices), lead to a myriad of new ubiquitous applications ranging from simple messaging systems to cyber-physical environments that may even encompass an entire city [4]. Making this prospect a reality, raises a number of challenges. One of these concerns the use of mobile computing as an underlying technology to supply collaboratively sensed data and social networking metadata for these ubiquitous services. In wide-scale urban scenarios, only using wireless infrastructures (e.g. cellular, WLAN, or WiMAX networks) to provide services is not satisfactory, as it is very unlikely that wireless infrastructures alone will be able to provide enough bandwidth and coverage for the huge number of devices spread throughout the environment [2]. Another important consideration is that current mobile computing applications are infrastructure-centric, which forces users to be acutely aware of their connectivity environment, with many applications only working when the networking infrastructure is available.

An alternative way of overcoming these limitations is the use of Opportunistic Networks. Opportunistic Networks are a recent mobile networking paradigm stemming from research into conventional Mobile Ad Hoc NET-works (MANET) [1]. In this paradigm, nodes are assumed to be mobile, and the forwarding of messages is based on the Store-Carry and Forward concept. Opportunistic Networks represent the first attempt to close the gap between human and network behavior by adopting a user-centric approach to networking and exploiting user nodes' mobility as an opportunity-rather than a challenge-to improve data forwarding [3].

A problem in this context is how to route data between nodes in a suitable way (i.e. with high delivery rate, low latency and low overhead). There are several initiatives which can be taken to meet these requirements. The proposed solutions involve adopting different approaches, ranging from “nave” (i.e. the use of “blindly” flooding techniques to reach the destination node) to “intelligent” (i.e. with an emphasis on social factors in routing messages). However, to the best of our knowledge, none of the existing studies has attempted to apply small-world network concepts [7] for this purpose. The idea of incorporating this class of complex networks in Opportunistic Networks is driven by the most recent studies of human mobility and social contacts; these are using graph models to better understand and represent the degree of social connection between people [6]. Hence, this paper aims to investigate the question of whether the “six degrees of separation” conjecture of small-world networks can be used as a basis for routing improvements in Opportunistic Networks.

In summary, the contributions made by this paper are twofold: first, there is a demonstration that static graph models are not suited to underlay routing approaches in highly dynamic networks (like Opportunistic Networks) without take account of temporal factors such as time, duration and frequency of encounters. Second, it shows that the application of these findings in a simple routing algorithm can surpass the performance of other algorithms in terms of the number of messages, delivery and overhead. In addition to being original, these features signal the direction for further research towards the application of some statistical or machine learning method to predict internal configuration values of routing algorithm using contextual or situational information of nodes.

The rest of this paper is structured as follows. The next section provides information about our approach to use small-world concepts in Opportunistic Networks; Section 3 presents our simulations scenarios and analyzes the results of the experiments; and, finally we conclude this paper in Section 4.

2. Small-world concepts in Opportunistic Networks

The “six degrees of separation” indicates the degree of separation between two nodes in a graph. This principle is also often spoken of as small-world phenomenon and was appointed by Watts & Strogatz [8] in some kinds of networks. Watts & Strogatz studied networks with low degrees of separation by carrying out a set of rewiring experiments on graphs and observed that a small world network can be found between a highly ordered network and a randomly connected network just by varying the randomness p of the network connections between regularity (p = 0) and disorder (p =1). A small-world network can be represented by directed or undirected graphs and is characterized by a high clustering coefficient C and a low path length L. These striking features have led us to analyze the application of small-world concepts in Opportunistic Networks as an alternative for routing messages.

Hence, after some successive experiments and refinements, we observed that just using a static graph representing contacts between nodes was not suitable. This fact is due to high dynamicity of the network resulting in obsolete edges over time. Therefore, we decided to apply temporal aspects of contacts of nodes in the graph. The result is a quite simple algorithm called Temporal Small World. It exploits the argument that each node is separated by, at most, six hops (six-degree conjecture) and uses the time of contact between nodes to periodically update the edges of the graph. The Temporal Small-World pseudo-code follows in Algorithm 1:

3. Simulation and experimental results

To evaluate the proposed algorithm we carried out simulations by using ONE Simulator (Opportunistic Network Environment Simulator[1]) with three public trace datasets (Realitty[2] , Infocom[3] and SIGCOMM[4]) and some popular routing algorithms for comparison. We choose Epidemic, Prophet, DRAFT and BubbleRap because they represent different classes of protocols and have been extensively studied by researchers. In the case of evaluation we adopt same performance metrics used by [5] to measure the performance of protocols (i.e. number of messages created, relayed, delivered and overhead ratio).

Some of the chosen protocols do not need configuration parameters, such as Epidemic. In others, we have to set it to run simulations. For Prophet we set secondsInTimeUnit = 30. For DRAFT we set familiarThreshold = 120, degrade = 0.5 and framesize = 3600. For Bubblerap we set K = 5, familiarThreshold = 700, centralityTimeWindow = 21600 and epoch_count = 16 (i.e. simulation time of 345600 seconds / centralityTimeWindow 21600 = 16).

3.1. Experimental Results

Our first experiment was to understand the implication of value of our algorithm variable maxAge τ in expiration of obsolete edges and how it would have an impact on the routing performance. In the simulations, we tested τ with values of 1800, 3600, 21600 and 86400 seconds (i.e. 30 minutes, 1 hour, 6 hours and 24 hours). The best performance in all of the scenarios was with lower τ values. This fact indicates our initial belief that obsolete edges really have an impact on message routing. After this, we carried out some simulations and plotted the performance of Temporal Small-

1 http://www.netlab.tkk.fi/tutkimus/dtn/theone/
2 http://realitycommons.media.mit.edu/
3 http://crawdad.cs.dartmouth.edu/meta.php?name=cambridge/haggle
4 http://crawdad.cs.dartmouth.edu/meta.php?name=thlab/sigcomm2009

Algorithm 1 Temporal Small-World

```
Given: every node n ∈ N
for t ← 1; ...; N do
    if node n_i find a node n_j then
        update edgeWeight_ij
        update edgeTime_ij
        if buffer of node n_i have a message m_k with destination to node n_k then
            if distance d_jk of n_j to n_k < 6 and edgeWeight_ik > κ then
                forward m_k to n_j
                remove m_k from n_i buffer
            end if
        end if
    end if
    for all vertice v of G do
        for all edge e with vertice j adjacent to v do
            if edgeTime e_vj > maxAge τ then
                remove edges e_vj and e_jv
            end if
        end for
    end for
end for
```

World with other selected protocols (Figure 1). It should be highlighted that although it produced +40% of overhead in some cases, when this criterion was adopted, Temporal Small-World was better than Epidemic and DRAFT in all the scenarios and either worse or better than Prophet and BubleRap, but in all cases with relatively similar results. With regard to the number of delivered messages, the results demonstrate that Temporal Small-World had the second best ratio in all the scenarios (Prophet was the first). What caught our attention was the number of relayed messages of Prophet that ranged from 19% (Infocom) to 213% (Reality) and was more than Temporal Small-World in all the scenarios. We recall that to relay messages, mobile devices use battery power for processing and data transmission; thus a high value of this indicator could influence the battery life of these devices. Another finding is the low number of relayed messages of BubbleRap that vary between 24% to 84%, which is less than Temporal Small-World. We believe that this ratio can be attributed to the strategy of only relaying messages to members of community of interest. However, we argue that this indicator could be better investigated in the light of issues arising from power, community detection and application of contextual information about nodes for routing decision in future research studies. In the final analysis, we believe that Temporal Small-World can overcome the Prophet results with fine tuning of maxAge τ and number of previously encountered κ variables. Nevertheless, owing to the wide range of factors involved in human mobility, this task could be better performed by some statistical or machine learning method that was able to predict the most suitable value.

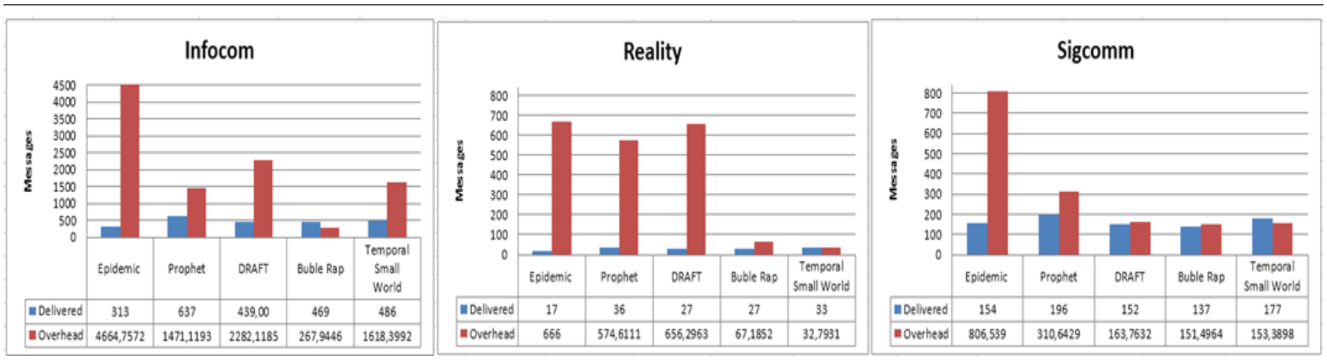

Figure 1. Performance of protocols in selected scenarios: (a)Infocom (b)Reality (c)SIGCOMM

4. Conclusion and Future work

Opportunistic Networks are able to exploit social behavior to build connectivity opportunities. This study analysed the feasibility of applying the concepts of small-world networks to improve routing. We proposed a simple approach based on small-world networks called Temporal Small World for routing and showed how it could outperform some popular protocols by means of simulations. It can be concluded that static graph models are not well suited to underlay routing approaches in highly dynamic networks like Opportunistic Networks without taking account of temporal factors such as time, duration and frequency of encounters. In future work, we will investigate which technique can be used to fine-tune max age τ and the number of previously encountered κ variables. We believe that a prediction of these values using contextual or situational information about nodes could improve the performance of our algorithm.

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