

Centrality Based Routing Protocol with Message Relay Control in Opportunistic Networks

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Abstract— Opportunistic Networks are a subclass of Delay Tolerant Networks (DTN), which aim at wireless data delivery in severely partitioned networks. There exist several protocols that route messages on a best effort basis. In most cases, the nodes copy and forward messages to nodes that are more likely to meet the destination. But, the major challenge is to design a routing protocol that offers the best tradeoff between cost (number of message replicas) and rate of successful message delivery. In this research paper, the tradeoff is being efficiently handled by using the concept of Google Pagerank like centrality to rank nodes in a network using social information. Unlike other nodes in the network, central nodes act as influential nodes to facilitate the message forwarding. Furthermore, to the centrality routing, a mechanism of message relay control is designed and linked to keep the network overhead ratio low. The proposed Centrality Based Routing Protocol (CBRP) with Message Relay Control algorithm was evaluated by simulations using the Opportunistic Network Environment (ONE) simulator. The results show that CBRP outperforms other typical routing protocols in Opportunistic Networks.

Keywords- Routing protocol; Centrality; Opportunistic networks; Overhead; message delivery.

I. INTRODUCTION

In recent years, incoming of smartphones and advent of wireless technologies make a seamless and cheaper communication between wireless devices anytime and anywhere. In this setting, Opportunistic Networks (OppNets) are considered as specialized ad hoc networks characterized by frequently intermittent connections, which operate without any assistance to any infrastructure, such as Access points, Routers etc. Communications in this type of network is made possible by mobile self-configurable devices, with no infrastructure assistance feature, exploiting direct contacts among nodes with a message Store - Carry and Forward way and incentive way to guarantee information exchange, as some nodes in a network tend to refuse to share their private resources, such as buffer space. Summarily network topology is not known a-priori, at the message sending. Therefore, routing protocols in such environment rely much on network assumptions, such as mobility patterns, node

capacity, scheduling knowledge, estimation and on prediction on the likelihood of future network topology [1].

Centrality is one way, among other routing protocol metrics used to forward the message in social opportunistic network. As the name expresses, centrality relates to action to identify central nodes in a network. Therefore, centrality definition should derive from various means, including social criteria. Due to the dynamics of node mobility, the influence that a node may have over the spread of information in relation to how many other nodes (encounters) this node may have been in contact with, has a significant implication in defining a centrality metric, in this work.

Based on this implication, each node in a network is assigned a centrality value using Google Pagerank like algorithm. In the proposed Centrality Based Routing Protocol (CBRP), the nodes with highest centrality values are more likely to act as the best message forwarders. The algorithm is simulated using the ONE simulator.

The rest of the paper is organized as follows: Section 2 describes a summary of the related works. Section 3 gives explanation on assumptions made on the CBRP. Section 4 deals with the design of algorithm and parameter metrics used for the evaluation of the proposed protocol. Section 5 concerns the analysis of the simulation results. Finally in Section 6, conclusion is made and the future works are recommended.

II. REVIEW OF THE RELATED WORKS

A common characteristic of routing protocols in opportunistic network is that they are replication-based, as the network topology is intermittent and not known a priori at the message sending. Consequently, the efficiency of any protocol relies much on what extent the protocol restricts message replication while maximizing a message delivery guarantee. Furthermore, most routing protocols are context-aware routing protocols, where the knowledge of the context in which nodes operate is used to identify the best next hop of a given node. Context aware based routing protocols are in turn, classified into mobility-based routing protocols, and social context-based routing schemes as the most of mobile devices are carried by humans. Furthermore, various social-based routing protocols have been proposed [2][3],

exploiting various social characteristics, such as community and centrality.

From the replication-based to context-aware based routing protocols, various routing schemes in OppNets evolved. Initially, Vahdat and Becker [4] proposed the epidemic routing protocol, a totally replicating and flooding-based, as nodes continuously replicate and transmit messages to newly discovered contacts to eventually reach the destination. It follows the variations of epidemic routing, such as Spray and Wait (SnW) routing protocol proposed by T. Spyropoulos, K. Psounis and C. S. Raghavendra [5] to impose the limit on the number of possible replications of a message and to maximize the aggregate resource consumption (for example, bandwidth and energy) in the network. In the latter, a particular message is spread to at most L different relay nodes. The nodes then perform a direct delivery when they come in contact with the corresponding destination of the message. In [6], A. Lindgren, A. Doria E. Davis and S. Grasic proposed the Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET) by ranking nodes encounters with a set of probabilities as the greater chance of encountering the destination. A flooding-based MaxProp [7] imposes the priority on a message by maintaining an ordered-queue based on the destination of each message and on the estimated likelihood of a future transitive path to that destination. In [8] the Resource Allocation Protocol for Intentional DTN routing (RAPID) is proposed, by exchanging the expected contact time with other nodes, list of messages delivered, and average size of past transfer events are exchanged.

Few social based forwarding that exploit the interplay between the structural properties of social networks and mobility aspects are pointed out: SimBet [9] that uses social network properties, such as betweenness centrality and social similarity to inform the routing strategy and (BUBBLE Rap) [10] that targets nodes with high centrality as well as members of the communities, yielding delivery ratios similar to flooding approaches with lower resource utilization.

It has been an age since various researches on network centralities in different domains, such as in sociology, biology, physics, applied mathematics and computer science. The computations of centrality in a DTN social network forwarding, the idea is related [11]-[16]. For example, when calculating the betweenness and closeness centralities of all the vertices in a graph involves calculating the shortest paths between all pairs of vertices. Therefore, many algorithms evolved to calculate the betweenness centrality, including Floyd-Warshall algorithm [17], and Baoqiang 's algorithm [18]. However, when investigating into the above centrality computing algorithms are centralized and rely on global information of the network as they rely on the knowledge of the network size.

Recently, distributed algorithms have been proposed in [19]-[21] for computing the betweenness and closeness centralities and other centrality measures are proposed in [22][23], to adapt the algorithm to dynamic characteristics of mobile wireless network. Different approaches were adopted

for computing Pagerank like centrality in mobile wireless environments, namely eigenvector centralities [24] and Peoplerank algorithm [25]. The latter, computes centrality inspired from Google Pagerank, both in a centralized and distributed way. Motivated by the above-mentioned works, this work proposes iterative algorithm to compute the distributed centrality adapted to Google Pagerank concept and opportunistic mobile network dynamics.

In the proposed CBRP algorithm, every node computes and evaluates its own centrality by using local interactions with only its current encounter without knowing the network size, and the network topology. Consequently, this fits well the opportunistic networks characteristics where network topology is frequently intermittent and change, especially when the network size becomes larger; it is usually very difficult to compute centrality measures. In addition to that, the CBRP inspired by Peoplerank algorithm, takes advantage of the fact that, a time- varying social graph, is iteratively built to reflect the dynamic of the opportunistic network, by the inference of social nodes from a node's encounters. The assumptions made from Peoplerank algorithm, as the interpretation towards this assumption inference will be given in the third Section. Assuming that only neighbors in the social graph have an impact of the popularity (i.e., the ranking), as the nodes meet, the node's centrality is updated and the number of neighbors is incremented by one to reflect the impact of a new social node. Consequently, the same idea in PeopleRank, is applied to tag people as "important" when they are linked (in a social context) to many other "important" people. The main concept originated from Google's Pagerank [26].

III. EXPLANATION OF THE ASSUMPTIONS MADE FROM PEOPLERANK ALGORITHM

PeopleRank is a social distributed routing algorithm measuring opportunistically the importance of a node in a social graph based on the social interaction between nodes and their contact frequencies using real human mobility. In other words, it tried to determine the optimal forwarding paths given the mobility patterns and their connectivity properties, to compute for the success rate as the delivery probability.

When investing the Peoplerank algorithm, 3 observations are noteworthy:

Firstly, the impact of the damping factor on the Peoplerank. It is used to control the amount of randomness forwarding in Peoplerank. Its value can be chosen and well adapted to social forwarding, according to whether the stated social relation is implicitly or explicitly declared, even though some randomized forwarding might be a little beneficial. As one of Peoplerank observation, in the 2 previous situations, the optimal value of d is around 0.87 and 0.8. Consequently, an assumption was made of using the damping factor of 0.86 to reflect the application of CBRP in a likely high social interaction and connection environment, as in the closed campus, where social rate is implicitly high.

Although a shared common interest is not an optimal social property to rely on, when selecting a best message

forwarding node, social based on being in a geographic location, as it was stated by Peoplerank (“Geographic location helps user to socialize more often and meet with each other more frequently”) and on implicit or explicit friendship are optimal, the CBRP will be then applied into a closed environment, such as in a campus.

Secondly, Peoplerank is compared to the following social based algorithms: Centrality, that forwards a message from u to v if, and only if, $C(u) = C(v)$. Here, $C(u)$ denotes the betweenness centrality of node u measured as the occurrence of this node in all shortest paths connecting all other pairs of nodes and degree that forwards a message from u to v if, and only if, $d(u) = d(v)$. Here, $d(u)$ denotes the degree of node u in the social graph (in a friendship graph, the degree is the number of friends of node u). Both Peoplerank and Centrality achieve a comparable result while they outperform the degree based, with a comparable success rate of a flooding-based Epidemic routing. Furthermore, Peoplerank is much preferred over the centrality-based, as the latter requires centralized computation, which is more complex to compute.

Therefore, as a higher impact and factor of the meeting event (to the Peoplerank performance) has been evaluated better (rather than above-mentioned social criteria) to improve the social patterns and node position in a social graph. An assumption is made to infer social nodes from the meeting event. This validates well the high implication of a meeting event into a social, as Peoplerank centrality update and increment as the nodes meet. Consequently, the distributed CBRP algorithm has been developed, by assuming that when the nodes meet, the node’s centrality is updated and the number of neighbors (inferred encounters) is incremented by one to reflect the impact of a new social node.

Thirdly, when Peoplerank is compared to well known contact-based algorithms (namely Last Contact, Destination Last Contact, Frequency, Spray & Wait and Wait-destination), it outperforms them. This is due to the social aspect of the algorithm that delivers the messages with higher probability to the destination. This validates the importance of a dynamic and distributive social to the selection of message forwarding.

Finally, the message forwarding of CBRP does not rely on network global structure, as it does not require the known size of the network, as it is the case in Peoplerank.

IV. ANALYSIS AND DESIGN OF THE PROPOSED ALGORITHM

To design the CBRP protocol, a model of an imaginary social graph is adopted, where a node itself in a network forms a graph vertex, and its predecessors and successors are its encounters. Extracting from meeting event, implicit social node attributes, such as being in a geographic location, being friends, the protocol aggregates this imaginary node’s social attributes into a contact graph. Therefore, the CBRP protocol computes for popularity of each node in a network, based on number of its encounters, inferred social nodes.

The CBRP protocol works as follows: When two nodes meet, one is considered as forming an incoming link to another node, and the nodes encounters as forming outbound links on the involved nodes. Then, the meeting nodes calculate and update their tables: Encounters table whose current number of encounters is increased by one and their centrality table get updated with newly calculated Pagerank like centrality. The Google Pagerank like centrality is calculated according to the following equation (delivered from Google PageRank):

$$C(i) = (1-d) + d(C(j)/T(j)) \quad (1)$$

where $C(i)$ is centrality of current node, $C(j)$ Centrality of encountered node and T_j is a number of encounters of node j and d which depend on how much the social relationship between nodes can help improving their centrality values.

It is clearly noted that Centrality in the network is calculated dynamically in time and in space, using a distributed algorithm, for which the total number of nodes are not initially known, therefore, much suitable to the dynamic wireless mobile environment. For simulation purposes, d has been set to 0.86.

More importantly, a message is delivered from node i to node j , if the centrality value of j is greater than or equal to that of i or j is the destination node.

Finally, each node maintains an acknowledgement table in the form \langle Message ID, Source ID, Destination ID \rangle , that contains information on message delivered to destination and that should be flooded among nodes in network. In fact, when two nodes meet, they should check for any new acknowledged messages in acknowledgement table of the encountered node, then update their buffer by removing a copy of it and update their acknowledgement table to spread the update information to other nodes in network.

A. Parameter metrics of the Algorithm

The performance metrics used to evaluate the developed protocols are:

- Delivery probability is defined as the number of successfully delivered messages divided by the number of created messages

$$\text{Delivery ratio} = \frac{\text{Number of Packets received}}{\text{Number of Packets sent}} \quad (2)$$

- Overhead ratio: This is a metric used to estimate the extra number of packets needed by the routing protocol for actual delivery of data packets. It can be defined as:

$$\text{Overhead ratio} = \frac{\text{Nr. of Packets relayed} - \text{Nr. of Packets delivered}}{\text{Nr. of Packets delivered}} \quad (3)$$

B. Algorithm for the CBRP protocol

Notations:

- i: Current node
- j: Encounter node
- E(i): Number of encounters of current node i
- C_i: Centrality value of node i
- Buffer(i): The buffer at node I
- M: Message currently being sent
- DN: Destination node
- Ack_table: Acknowledgement table
- Ack_M: Acknowledgement message

1) Algorithm1

- Step 1: select the next Encounter node j
- Step2: If j is busy then go to Step1
- Step3: Repeat all messages (M) of current node i
 - 3a: If j has M then go to step 3 to select the next Message
 - 3b: check Ack_table of j for M
If Ack_Table of j has M then
Remove M from buffer of i
Update Ack_table of i
Go to step 3 for next M
End if
 - 3c: If C_j >= C_i or j is equal to DN then
Forward M to j
End if

Algorithm related to Acknowledgment:

2) Algorithm2

When a destination node is receiving a message:

- Step1: Receive message (M) from the Last Sender Node(LSN)
- Step2: If Destination Node(DN) of M is current node i then
Create and Send Ack_M to LSN
Update Ack_Table of i with Ack_M
Remove M from the buffer of i
End if

3) Algorithm3

When the last sender is receiving the acknowledgement:

- Step 1:Receive Message (M) from the Destination Node (DN)
- Step 2: If M contains ACK_M then
Update Ack_Table of i with ACK_M
Remove M from the buffer of i
End if

C. Flowchart for the CBRP protocol

The flowchart is given in Figure 1.

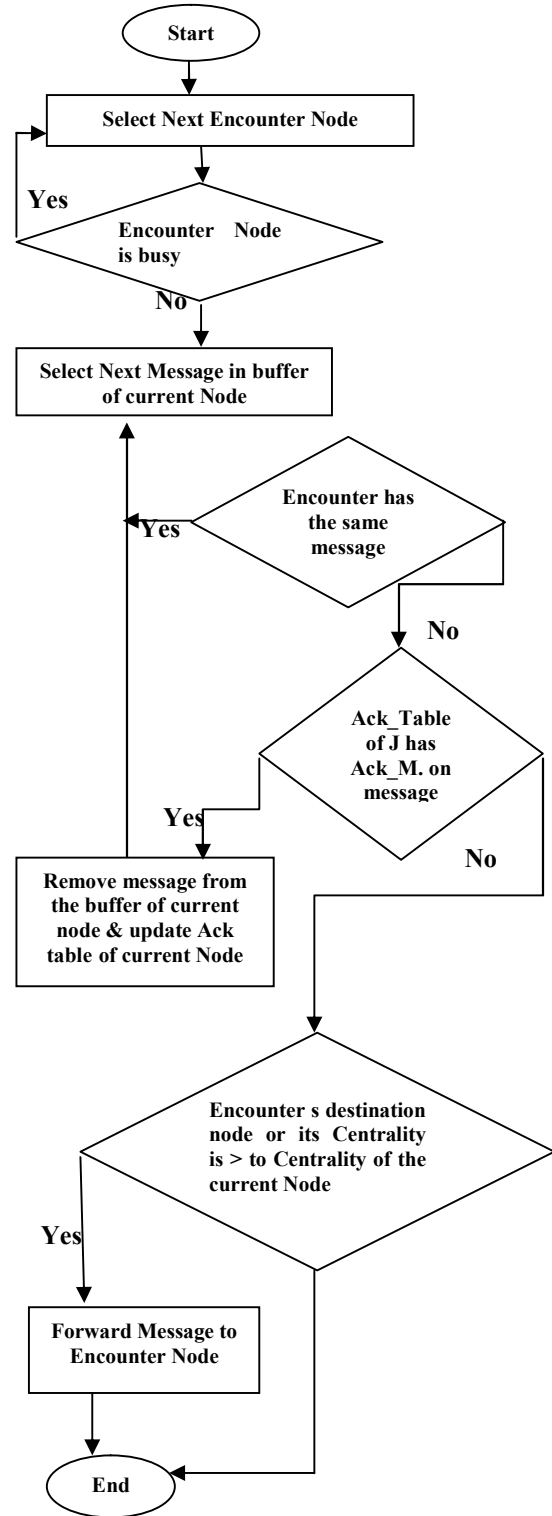


Figure 1. Flowchart for the CBRP protocol.

V. SIMULATION RESULTS AND ANALYSIS

The proposed protocol CBRP is evaluated by Random Scenario simulations and compared against the standard routing algorithms including: Epidemic, due to its potentially high message delivery, PROPHET due to its probabilistic routing and MaxProp due to its predictability routing with acknowledgement. The simulations focused on the performance metrics: Delivery Probability and Overhead Ratio. The simulator used is the ONE simulator version 1.6.

A. Simulation setup

The simulation parameters used are shown in TABLE I.

TABLE I. SIMULATION PARAMETERS

Simulation parameter	Value
Routing Protocol	CBRP, Epidemic, Prophet, Maxprop
Number of nodes groups	1
Number of nodes	Variable(36,72,100,130,170)
Mobility Model	RandomWaypoint
Simulation Time	43200 secs
Simulation Area	(4500X3500)m
Time-To-Live(TTL)	Variable(100,150,200,250,300) minutes
Node speed	0.5-1.5(meters/sec)
Scenario.updateInterval	0.1
Interface type	Bluetooth/Simple broadcast interface
Transmit speed	2Mbps(250kBps)
Interface transmit range	10 meters
Size of the message buffer	5MB
seed for movement models	1
Number of event generator	1
Class of event generator	MessageEventGenerator
Creation interval of event	A new message every 25-35 seconds
Message size	500KB-1MB

B. Simulation running

Figure 2 shows the simulation environment where, as the nodes are moving, messages created, relayed, dropped and delivered are calculated to generate the report file at the end of the simulation. The latter contains the standard results, such as the Message Delivery Ratio, Average Latency, the network overhead, the Average Number of Duplicate Messages, and many other network statistics, used to produce the following plots:

- Plots of message delivery ratio as a function of number of nodes
- Plots of message delivery ratio as a function of message TTL
- Plots of network overhead ratio as a function of number of nodes
- Plots of network overhead ratio as a function of message TTL

Each simulation includes 20 scenarios, run for once and under the same values for parameters, to be able to compare 4 routing protocols with five values for a variable TTL/ number of nodes. This validates and maintains the performance assessment.

C. Simulation analysis

1) Analyzing the delivery ratio

Although flooding is controlled, which normally is the technique to achieve a higher delivery ratio, CBRP is comparable to flooded-based Epidemic and Maxprop, whereas it outperforms a probabilistic Prophet. This is attributed to the fact that CBRP is likely to produce a better forwarding path to deliver the messages to the destination; as the path is formed with nodes that are likely characterized by high centrality values compared to nodes that are not part of the routing paths. Therefore, CBRP has a better metric to select a relay node that is likely to meet the destination, than Prophet routing. Additionally, for the 4 routing protocols compared, as TTL increases, the delivery ratio increases. This is attributed to the fact that when TTL increases, the message remains in the buffer for a longer period of time, leading to a higher chance to meet the destination.

2) Analyzing the Overhead ratio

For the 4 protocols, it is observed that when TTL increases, the overhead ratio decreases. This is due to the fact that the message remains for a long period in the buffer. This way, messages are not dropped on the way to their destination and consequently no need to be replicated which results to a low overhead ratio. Therefore, the lesser relay messages, the better the overhead. It is observed that under varying number of nodes and varying TTL, the CBRP outperforms Prophet, while the flooded Epidemic and Maxprop achieve higher overhead ratio.

The CBRP is compared against 4 aforementioned protocols. The results are depicted in Figures 2, 3, 4 and 5.

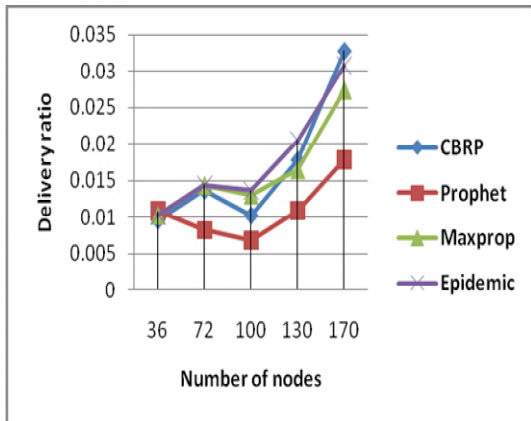


Figure 2. Comparison of CBRP, Epidemic, MaxProp and Prophet for varying number of nodes.

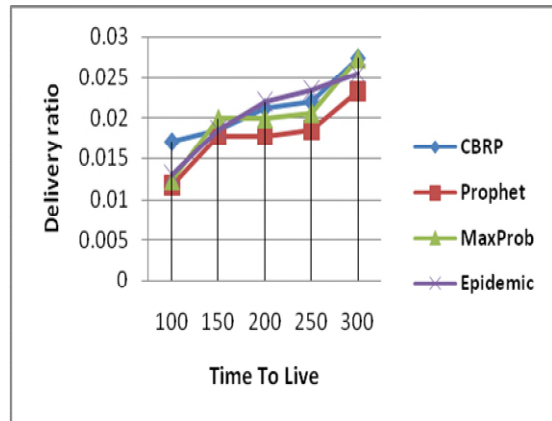


Figure 3. Comparison of CBRP, Epidemic, MaxProp and Prophet for varying message TTL.

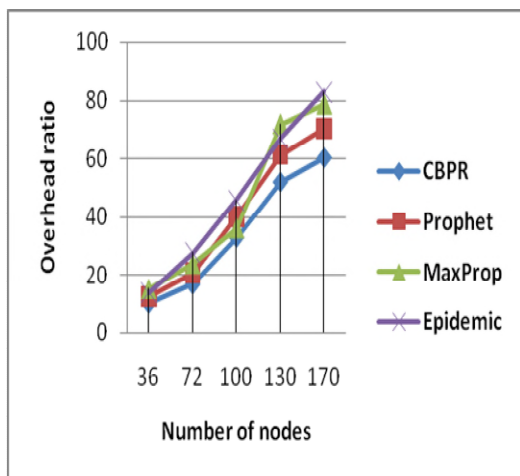


Figure 4. Comparison of CBRP, Epidemic, MaxProp and Prophet for varying number of nodes.

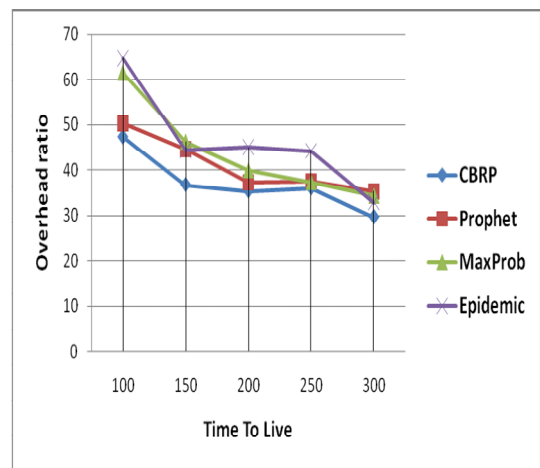


Figure 5. Comparison of CBRP, Epidemic, MaxProp and Prophet for varying message TTL.

VI. CONCLUSION AND FUTURE WORK

In this paper, a CBRP protocol for OppNets has been developed which uses the Centrality concept for the message forwarding process. Simulation results on the performance of CBRP in comparison with Epidemic, Prophet and MaxProp under the same experimental conditions have revealed improvement that cannot be ignored, both in terms of a message delivery ratio and overhead ratio. Therefore, a developed model could be a choice to follow for a message forwarding in opportunistic networks. However, as for recommendation, two things are mentioned. On one hand, the tests performed here were limited to the random scenario simulation as the Randomwaypoint movement model of nodes was used. Due to this, it can be recommended to test the developed protocol under human scenarios and other recurring pattern based structures to explicitly show how well CBRP routes message under realistic mobility scenarios. On other hand, the developed CBRP protocol can be enhanced with new capabilities that deserve attention in a network routing, such as security and privacy.

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