

Max-Pivot Routing for Opportunistic Networks

Tamer Dag

Computer Engineering Department
Kadir Has University
Istanbul, Turkey
tamer.dag@khas.edu.tr

Abstract—Opportunistic networks are challenging types of networks where network connections are imminent. Network topologies are dynamic and can rapidly change. A path between a source node and a destination node may or may not exist, the network can be disconnected. This type of behavior observed under opportunistic networks makes classical networking solutions impractical. Thus, traditional routing algorithms are not suitable for such networks and will not be useful. Although flooding might be seen as the best solution to reach a destination under opportunistic networks, flooding solutions' extensive usage of network resources is an extreme overhead. In this paper, max-pivot routing for opportunistic networks is proposed and described. With max-pivot routing, it is observed that the induced network traffic is significantly reduced while still achieving the benefits of a flooding based routing. The performance comparisons of max-pivot routing and flooding based routing methods show that max-pivot routing can be a successful routing method for opportunistic networks.

Keywords: *Opportunistic network, routing, flooding*

I. INTRODUCTION

Opportunistic Networks are one of the new and developing research areas of Wireless Sensor Networks (WSNs) and Delay Tolerant Networks (DTNs). Under Opportunistic Networks, there is no regular communication and communication is imminent in the network. An end-to-end path between a source node and a destination node may or may not exist; sometimes an end-to-end path may never exist due to the non-collaborative behavior [1] in the network. In addition, limited resources such as energy, bandwidth, memory, etc. make transmission of messages difficult. As a result, message transmission and routing for opportunistic networks is an extremely difficult task and in some conditions messages might never be delivered. Therefore, forwarding algorithms should focus on robustness and reliability of message transmission instead of performance.

Although Opportunistic Network structure can be used in such areas like Military, Industrial, Ecological Monitoring, Undeveloped areas (villages, remote towns, etc.), Biomedical, and Car-Based Ad-Hoc networks [2,3], the fore mentioned issues would make classical routing approaches insufficient and unusable for opportunistic networks. The routing algorithms used in Opportunistic Network topologies should

be dynamic and should try to make a message transmission possible in its maximum extent.

There are many different routing protocols proposed for the dissemination of packets between nodes in MANETs (Mobile Ad-Hoc Network), but there are issues like forwarding packages between mobile nodes. For that reason, two different opportunistic routing/forwarding infrastructures [4] might be built:

- Without Infrastructure :
 - Dissemination Based [5]: Dissemination based routing propagates messages between nodes in the network, every node in the reached area spreads the messages constantly until the destination is reached. A well known effective solution in disconnected, large scale and sparse systems for dissemination based routing is Epidemic routing [6]. It mimics the spread of infectious disease where infected individuals pass on a virus to those with whom they come into contact. By allowing the packet to spread throughout the mobile nodes, the delay until one of copies reaches the destination can be significantly reduced [7], but it increases the network traffic overhead.
 - Context Based Routing [8]: It reduces the messages` duplication but increases the message delivery ratio and also increases the computation costs. CAR (Context Aware Routing) is one method of context base routing skill. By using acknowledgements, the delivery ratio between nodes is exchanged periodically and the best valued ratio delivers the messages to other nodes.
- With Infrastructure
 - Fixed Infrastructure [9]: In fixed infrastructure, base stations are needed. Generally a source node requires delivering its message to a base station which is the gateway. Thus, the source stores the message until it encounters with a base station but it also spreads its messages to other nodes, to find the gateway more quickly. Such a

routing protocol is used in SWIM (Shared Wireless Infostation Model)

- Mobile Infrastructure [10]: In mobile infrastructure, carriers are provided to increase the connectivity in the network. The messages are collected by the carriers in that area and forwarded to other nodes. Such routing methods are Data-Mules and Ferriers.

A dissemination based routing protocol is flooding based algorithm and might suitable for an opportunistic network environment at a cost of extensive usage of network resources. The other mentioned routing protocols would not be suitable for Opportunistic Networks as for Opportunistic Networks, the device complexity and the node behaviors [11] are primarily critical factors.

In this paper, max-pivot routing protocol is proposed as a solution of routing problem for Opportunistic Networks. Section 2, summarizes our prior related work on routing with the description of flooding, partial flooding and max-pivot routing. Section 3 explains our simulation model and presents the results along with the comparison of max-pivot routing and flooding based routing solutions. Finally, Section 4 concludes the paper and summarizes future work.

II. ROUTING ALGORITHMS FOR OPPORTUNISTIC NETWORKS

In this section, some routing solutions for opportunistic networks are discussed and described. These routing solutions might be classified as flooding based solutions. Under a flooding based routing solution, multiple copies of a message are generated and forwarded to the neighboring nodes where the neighboring nodes repeat the same procedure until the destination can be reached or the message is expired and deleted. The basic characteristics of a flooding based solution are its simplicity, low delay, low cost but high induced network traffic. By introducing the partial flooding and max-pivot routing, we have aimed to significantly reduce the induced network traffic while still achieving the benefits of flooding.

A. Flooding

Flooding is the basic broadcasting method to reach any node in a network or in a subnetwork. Routing can be very difficult for opportunistic networks due to its intermittent behaviour. An end-to-end path between a source and a destination may or may not exist. Thus, flooding can be considered as one of the most promising methods to transmit a message to a destination node under opportunistic networks. Flooding has the best chance that a copy of the message will reach the destination robustly and reliably even when the network topology is dynamic.

Under flooding, a source node creates multiple copies of the message that it tries to transmit it to a destination node and

forwards it to all of its neighboring nodes as illustrated in Figure 1.

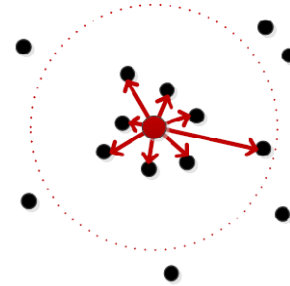


Figure 1: Flooding

A node which receives this message forwards it to its neighboring nodes and the message is quickly spread throughout the network. The destination receives the message if it is not in a separate disconnected network with the source node. Under flooding, any node in the network may receive the same message multiple times, but in such a case these nodes will not broadcast the message repeatedly and stop transmission to prevent infinite loops and excessive network traffic. However, even with by preventing infinite loops, the traffic overhead and the bandwidth consumptions are very high under flooding.

B. Partial Flooding

Partial flooding [12] can be considered as an alternative method for reducing the traffic overhead that occurs in flooding. The idea under partial flooding method is to transmit the message only to a subset of the neighboring nodes so that the network traffic can be reduced.

Under (p-percent) partial flooding, the source node or any node that receives the message randomly selects p% of its neighbors and transmits the message only to those neighbors. A node receiving the message for the second time ignores the message and stops its transmission. Figure 2 illustrates an example of 50% partial flooding. The center node with the plotted range has 8 neighbors inside its range, but unlike flooding, the node randomly chooses 4 neighbors and transmits the message to them.

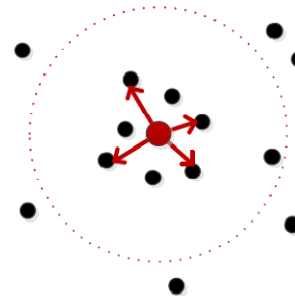


Figure 2: Partial Flooding

The impact of random selection of neighboring nodes is currently under study.

C. Max-Pivot Routing

Since flooding consumes network resources extensively, we have proposed two alternative methods for flooding. With partial flooding as described in the previous subsection, it is observed that the network traffic is reduced as compared to flooding. However, our simulations have indicated that the generated network traffic can still be extensive. Thus, we have proposed the max-pivot routing method which can significantly reduce the network traffic.

The max-pivot routing aims to transmit a message to a destination node by selecting a single neighbor node as opposed to flooding and partial flooding methods. The selection of the neighbor node is carried out by choosing the neighbor node which is the farthest to the transmitting node and inside its range as illustrated in Figure 3. The aim of choosing the farthest neighbor is to increase the chances of reaching the destination node as fast as possible with reduced number of hops and transmission delay. In addition to the farthest node, the transmitting node randomly selects a node in its range as a pivot and transmits a copy of the message to the pivot as well. Thus, the message is transmitted to only two neighboring nodes. Every node in the network that receives the message repeats this process to transmit the message to its destination.

The reason for choosing a pivot node is to increase the accessibility ratio because only choosing the farthest node for transmission may result in loops and termination of transmission. For example, if node A's farthest neighbor is B, node B's farthest neighbor is C and node C's farthest neighbor is A, the routing algorithm without a pivot would transmit the message from A to B, then B to C and then C to A. Since node A is receiving the message for the second time, it would stop transmission although the destination could have been reached from a node in the network.

Our simulation studies as discussed in the next section have shown a significant level of improvement with max-pivot routing.

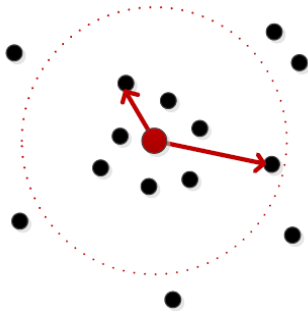


Figure 3: Max-Pivot Routing

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If the message is received for the first time
  If the destination is within the range
    Deliver the message to the destination
  End
  If the destination is not within the range
    Determine the set of all neighboring nodes
    Select the farthest node
    Select a random node (pivot node)
    Forward the message to the farthest node and the
      pivot node
  End
End
If the message has been received before
  Drop the packet
End

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Figure 4: Max-Pivot Routing Algorithm

Figure 4 illustrates the max-pivot routing algorithm for any node in a network.

III. SIMULATION MODEL AND RESULTS

In this section, the simulation model and the results for max-pivot routing for opportunistic networks are described. The results for max-pivot routing are also compared with flooding and partial flooding methods.

A. Simulation Model

The simulations for performance analysis of different routing algorithms are developed in C++ language by using Microsoft Visual C++ Express Edition IDE. For the simulations, an area of 1000m x 1000m has been selected and various numbers of nodes have been placed in this area. The location of the nodes, thus (X, Y) coordinates, has been picked up from uniform distribution. In order to see the impact of non uniform distribution of nodes on the routing algorithms, normal distribution is also used for placing the nodes in the given area. By this way, the effect of concentrated nodes in various regions of the selected area on routing algorithms is observed.

In addition to these nodes, two nodes marked as the source node and the destination node, have been placed at coordinates $(0, 0)$ and $(1000, 1000)$. The source node transmits a message to a destination node by flooding and our proposed partial flooding and max-pivot routing algorithms.

The simulations are based on discrete-time event simulation [13] in which the state variables change only at a discrete set of points in time. For our simulations, there are two primary events that trigger each other. One of them is the transmission of a message and the other one is the reception of a message. The events are managed through an event scheduler. An event scheduler is a dynamic list and the events are listed according to their event execution times.

A message is transmitted from the source to the destination node by using the routing algorithms described in the previous section. In order to compare the performances of these

algorithms, some parameters have been used for evaluation purposes. These parameters are:

- Average total delay between the source and destination nodes,
- Average number of hops between the source and destination nodes,
- Average total induced network traffic.

Each simulation has been run multiple number of times and the averages for the simulation results have been obtained for the above parameters by varying the number of nodes ($N=250, 500, 750$ and 1000) and node's ranges.

To calculate the total delay between the source node and the destination node, the processing delay at a network node is assumed to be equal to $t_{proc} = 0.05$ sec, and the transmission time of a packet from a node to a neighboring node is calculated based on the formula, $t_{prop} = d/C + p/R$.

In the above formula, d represents the distance between the two nodes, C represents the speed of light, p represents the size of the packet and R is the transmission rate in the channel. In all the simulations, packet sizes are assumed to be constant and equal to 1000 bytes. Transmission rate in the network is 100 Kbytes/sec, and all the nodes are identical to each other.

B. Simulation Results for Max-Pivot Routing

In this subsection the simulation results are presented for max-pivot routing.

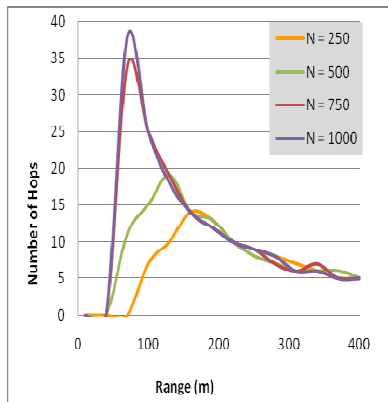


Figure 5: Hop Count

Figure 5 illustrates the simulation results for the hop count for the message to reach from the source node to the destination node under max-pivot routing as the node ranges vary. The simulations are conducted for $N = 250, 500, 750$ and 1000 nodes. For small node ranges, the likelihood of having a disconnected network increases and sometimes no connection is possible between the source and destination

nodes. Therefore, the message cannot arrive to the destination. When we have connectivity and as the node range increases, the hop count decreases. However, the number of nodes on the hop count is not significant for large ranges as max-pivot routing only selects two neighboring nodes in any case.

Figure 6 illustrates the simulation results for the induced network traffic as a result of max-pivot routing as the node ranges vary. The network traffic is the total number of messages generated for transmission of a single message from a source node to a destination node. The simulations are conducted for $N = 250, 500, 750$ and 1000 nodes. An increase in the number of nodes available in the network increases the network traffic as the message traffic increases proportionally with the number of nodes. When the node ranges are small, there is no communication between nodes due to disconnected subnetworks, so there is no network traffic. Increasing the node ranges on the other hand reduces the total induced network traffic as the destination can be reached more easily.

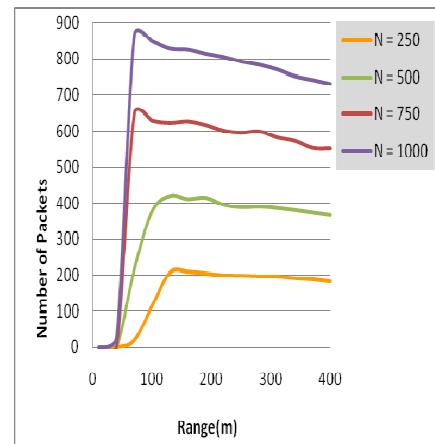


Figure 6: Network Traffic

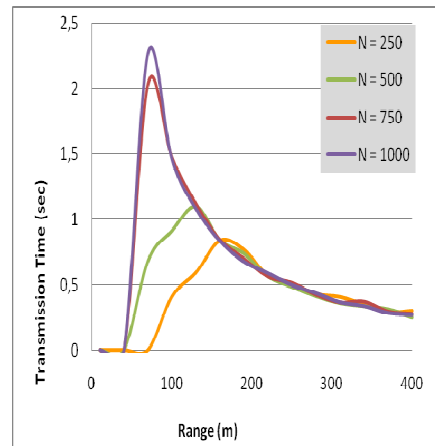


Figure 7: Total Transmission Time

Figure 7 illustrates the simulation results for the average transmission time of the message from the source node to the destination node as node ranges vary. The simulations are conducted for $N = 250, 500, 750$ and 1000 nodes. As the node range value increases, transmission time decreases because of the decrease in the number of hop count. The most important factor causing the delay is the number of message transmissions as the message propagates toward its destination, thus when the hop count decreases, it will result in a decrease of total transmission time. As expected, the hop count and total transmission time figures are very similar in shape.

C. Performance Comparison of Max-Pivot Routing

In this subsection, the max-pivot routing is compared with flooding and partial flooding methods in terms of hop count, induced network traffic, transmission delay, accessibility ratio and simulation run time, so that the advantages or disadvantages of the algorithms can be observed more clearly.

Figure 8 illustrates the simulation results for the average network traffic as a result of flooding, %50 partial flooding and max-pivot routing (uniform and normal distribution) as node ranges vary. The simulations are conducted for $N = 500$ nodes. From the results, it can be observed that the traffic generated in 50% partial flooding is almost half of the traffic generated in flooding algorithm. In addition, it can be seen that the network traffic induced for max-pivot routing is significantly reduced. This result is very crucial and important for max-pivot routing, because once data transmission is possible between a source node and a destination node, max-pivot routing can provide data communications with a considerably less usage of network resources.

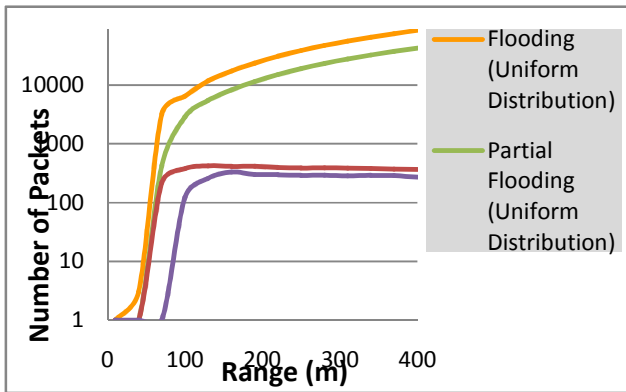


Figure 8: Comparison of Network Traffic

For example, for a node range of 200 meters, max-pivot routing would cause the distribution of around 420 (300) messages for uniform (normal) distribution, compared to 23500 messages of flooding and 12000 messages of 50% flooding. The difference in induced network traffic increases more with the increased range. In a similar manner, an increase in the number of nodes shows that max-pivot routing outperforms flooding or partial flooding methods.

Figure 9 illustrates the simulation results for the average hop count as a result of flooding, 50% partial flooding and max-pivot routing, as the node ranges vary. The simulations are conducted for $N = 500$ nodes. As one compares the hop counts for the different algorithms for a given range, it can be seen that flooding has the least number of hops. However, the difference between flooding and the other algorithms are only minimal. As opportunistic networks are delay tolerant, the difference can be considered as negligible.

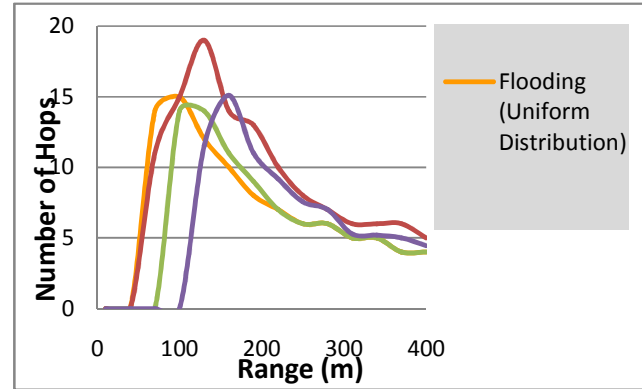


Figure 9: Comparison of Hop Count

Figure 10 illustrates the simulation results for the average transmission time of the packet from the source node to the destination node as a result of flooding, %50 partial flooding and max-pivot routing, as node ranges vary. The simulations are conducted for $N = 500$ nodes. When the values for flooding, %50 partial flooding are compared, it can be observed that they are very close to each other and similar to the hop-count comparisons. While the transmission time for max-pivot routing is slightly more than flooding and %50 partial flooding, the benefit of reducing the network traffic is far more important.

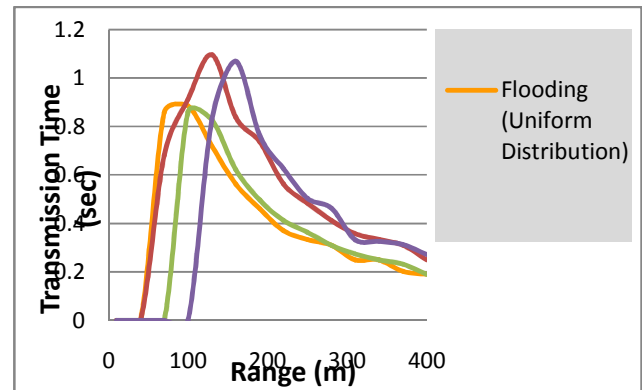


Figure 10: Comparison of Total Transmission Time

Figure 11 illustrates the accessibility ratio of flooding, %50 partial flooding and max-pivot routing algorithms. When the transmission range is high, the destination can be reached with 100% probability. For smaller ranges, flooding is a bit better although the values are considerably close to each other. When normal distribution is applied for node placement, the

likelihood of having a disconnected network increases and accessibility ratio is lower. However, this result also applies to flooding and partial flooding.

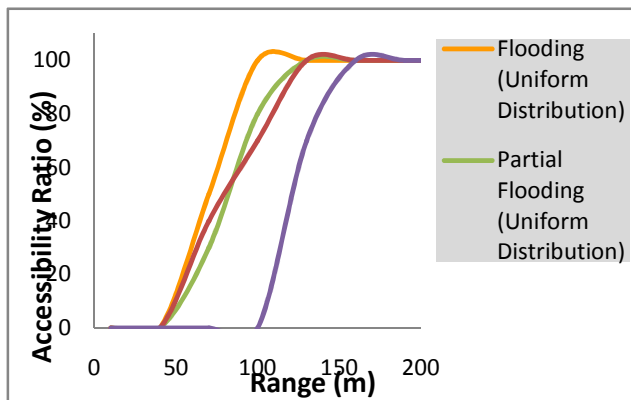


Figure 11: Comparison of Accessibility Ratios

IV. CONCLUSIONS AND FUTURE WORK

In this paper, the max-pivot routing for Opportunistic Networks is introduced and compared with the flooding and partial flooding algorithms.

Due to the nature of Opportunistic Networks such as intermittent connectivity, unreliable connections and rapid changes in topology, routing is a difficult task for such networks. Although, at first glance flooding based solutions could be seen as an appropriate way for solving the routing problem, the amount of overhead that flooding introduces can not be acceptable in most situations. With flooding based solutions, it is possible to reach a destination with the minimum delay and minimum number of hops. However, the amount of induced network traffic is extreme and can not be suitable for most cases.

In this paper, the max-pivot routing for Opportunistic Networks is proposed. The main advantage of max-pivot routing is the substantial decrease of induced network traffic seen in flooding based methods, making it a suitable routing algorithm for Opportunistic Networks. Although, the transmission delay, the number of hops needed to reach a destination can be slightly larger than flooding based methods, the delay tolerant nature of Opportunistic Networks can

compensate for these types of losses, as the main idea is to establish a communication without regard of delay.

In our studies so far, we have assumed that all the network nodes were identical. However, we will analyze situations where nodes are different with separate characteristics. For example, while some nodes might be willing to transfer data, some other would not. While some nodes might have a larger range, some might have a smaller range. These kinds of aspects will further be investigated to clearly understand the applicability of max-pivot routing for various scenarios.

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