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EVALUATING ROUTING PERFORMANCES IN MOBILE OPPORTUNISTIC NETWORKS USING DIFFERENT WIRELESS COMMUNICATION TECHNIQUES

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Abstract: Mobile opportunistic networks help users gain the advantage of accessing an available network connection for communication in rural areas or in high interference zones. Using local user's social interactions and communication platforms, users in such networks store, carry and forward messages between each other within a fairly close distance. In this paper, we examine how different wireless networking technologies affect the network performance. We use real-life trace driven simulations to evaluate their effects on the routing performances within the network. Furthermore, our intention is to study whether different communication ranges influence data forwarding in the mobile opportunistic networks. Our results show that local user's social interactions and collaborations help to improve the overall message delivery performance in the network. Moreover, we note that a higher communication range improve the overall message delivery performance but when communicating in a shorter range, users' interactions and collaborations are significant for data forwarding.
Keywords: Mobile opportunistic networks, routing performance, communication range

1. INTRODUCTION

Mobile opportunistic networks [10] are one kind of improved mobile ad-hoc networks that support delay tolerant networking [4] by exploiting the node's mobility for connectivity opportunities. Nodes in a mobile opportunistic network rely upon other nodes for message forwarding by means of spontaneous connectivity between the devices. There is no fixed infrastructure for communication and the non-existence of the end-to-end communication protocols due to the lack of network topological information [2]. In a given time, it is also possible that the source and destination nodes might never be connected to the same network [11]. The routing decision is taken locally during runtime by the nodes. Human interactions make significant impact to the network performance in such networks [14]. User's willingness for cooperation and their mobility patterns are major issues with this type of communication because they exploit the ubiquitous wireless communication capabilities of smart mobile devices [3]. Therefore, routing in mobile opportunistic networks is crucial for delivering messages from one node to another. The routers between the nodes create paths dynamically and adjust accordingly when the opportunity arises to bring the messages closer to their intended destinations [8].

In this paper we have analyzed the routing performances within such networks with two different wireless networking technologies. They are Bluetooth and Wi-Fi wireless networking technologies. Bluetooth is a wireless technology standard for communicating in a shorter range, typically 10 meters. Whereas, Wi-Fi is a local area wireless networking technology for communicating in a range of typically 100 meters [13]. Our intention is to see the overall message delivery performance in a mobile opportunistic network when we vary different communications ranges in the network. We performed real-life trace-driven simulation studies to see these differences. When this paper critically analyzed the different performance metrics to understand the different routing protocols and related message delivery performance, we address the following research questions:

1. How the different communication ranges vary the routing performance in a mobile opportunistic network?
2. Is there any significant impact made to the overall message delivery performance in the network due to the varied communication ranges?
3. How do the users' collaborations and social interactions improve the message delivery performance when varying these communication ranges in the network?

The aim of this paper is twofold, first we very different wireless communication techniques to see the overall changes in routing performances in the network and second to collate the information to understand how user's social interactions significantly impact the overall network performance. The major contributions of this paper are as follows:

1. We use Bluetooth and Wi-Fi wireless communication techniques to see the impact of different communication ranges to the routing performance in a mobile opportunistic network.

2. We use real-life trace-driven simulations to see the user's behavior and their impact on message forwarding.
3. Our experimental results show the potential for user's willing to actively collaborate in message forwarding in a shorter range, which improves the overall message delivery performance in the network.

The rest of the paper is organized as follows: We describe the state-of-the-art research in this area in Section 2. We then present the simulation setup and its various settings and results in Section 3. We discuss future research directions in Section 4 and conclude.

2. RELATED WORK

In this section we present the state-of-the-art research that combines user's mobility patterns and different routing techniques for data forwarding in a mobile opportunistic network.

Nakamura et al. presents a model for collecting information during disaster time, by taking into consideration the user's realistic mobility patterns [12]. A simulation-based experimental study has been performed to evaluate the proposed information gathering model during the time of a disaster. In addition with the user's mobility, authors also proposed an autonomous adaptable protocol combining the geographical routing in mobile ad-hoc networks (MANETs) and the store, carry and forward scheme in mobile opportunistic networks. Unlike the Nakamura et al. proposal, our proposal addresses and shows how different communication ranges may affect the network performance.

Hummel and Hess presents a mobility-pattern based approach for message communication in mobile opportunistic networks [7]. Using user's different behaviors and characteristics (e.g., evening activity, shopping, etc.) a simulation-based study has been performed to see the effect of opportunistic forwarding in the network. This study is mainly done with the two different forwarding metrics called short connection time and long connection time. Similar to [12], this approach also takes into consideration user's mobility patterns for information interchange. But unlike the present scope of our research, how different wireless communication technologies affects routing as well as affecting the overall message delivery performance in the network, is not discussed.

In [6], authors discuss the concept of Pocket Switched Networks (PSN) which connects nearby mobile users for information interchange in a delay tolerant manner. An in-house (an academic working environment) experiment is carried out with the Bluetooth enabled devices for collecting the real-life users' traces of forty one participates in a conference, to monitor their mobility patterns. This research focuses on the environment that may lack an end-to-end network topology for connectivity between the mobile users. In PSN, instead of finding an end-to-end path between the source and destination, nodes forward data with hop-by-hop using the user's mobility patterns. But unlike the scope of our research, this research does not present the view of how these mobility patterns affect the overall routing performance in the network with different wireless communications ranges.

A social-network based mobility model is described in [11]. In this model, authors explore the idea of social networking for specific node groups according to their higher 'social attractivity'. The 'social attractivity' is defined as the number of friends in a specific area at a certain time. However, this can be changed according to the user's movements (e.g., fast or slow), daily life routine (e.g., going to a specific restaurant or shopping center), as well as on the time of the day (e.g., office time is good to meet with colleagues but in the evening time a person may want to share his/her time with their other family members). While this paper focuses on the social connectivity for information interchange, it does not focus on the impact of different wireless networking technologies that can be used by the users. Our research aims to find and address the gap in this state-of-the-art research and explore the overall message delivery performance in a network in different wireless communication ranges.

3. SYSTEM MODEL AND PERFORMANCE EVALUATION

In this section, we evaluate the performance of different opportunistic routing protocols with real-life trace-driven simulations. In this, we simulate our own University town, St Andrews. For the simulation purpose we use two sets of node groups in the network, they are referred to as the local node group (LN) and the tourist node group (TN). The LN represents the local users who are familiar with places (e.g., shopping centre, library, information centre, etc.) in the town. The TN represents the tourists who are travelling to those places. We use two different wireless network technologies (i.e., Bluetooth and Wi-Fi) for this simulation.

3.1. Performance Metric and Simulation Setup

We use the opportunistic network environment (ONE) simulator to simulate our proposed experiment [9] over a period of one day. LN uses the real-life user traces. We use St Andrews 'SASSY' traces for this purpose [1]. This trace is collected by the movements of 27 participants (22 undergraduate students, 3 postgraduate students and 2 members of the staff) over a period of 79 days in St Andrews town. Participants are equipped with 802.15.4 'Tmote Invent sensors and tracker' for this purpose within a radius of 10 metres. TN generates message into the network and both the TN and LN were willing to share and forward these messages until they reached their indented destinations while both the TN and LN are moving within the network. The network consists of 60 nodes in total (27 LN and 33 TN) and we assume that they all are trusted. The TN node group moves with the 'shortest path map-based movement' model in the network. We impose some 'points of interests' (POIs) for the TN. These POIs are assigned in some significant spots throughout the town (e.g., St Andrews Cathedral, St Andrews Castle, St Andrews museum, Old Course Golf centre, etc.) where tourists visit more frequently. In the case of LN, we do not impose any synthetic characteristics because our intention is to make the system purely rely upon the real-life mobility traces, to see the potential impact of users' interactions and social communications in data forwarding. Table 1 summarizes the list of simulation parameters used in the experiment.

For the experiment purpose, we varied the wireless communication technologies to see the potential changes to the overall message delivery performance to the network. In the first set of experiments we used 'Bluetooth' communication techniques (within a range of 10 meters) for all nodes and we used 'Wi-Fi' communication techniques (within a range of 100 meters) for all nodes for the second set of experiments.

Table 1. Simulation parameters

Parameters	Values
World size	4500m X 4500m
Simulation time	1 day (24 Hours)
Node's movement model	Shortest Path Map Based Movement
Node's buffer size	200MB
Transmission medium	Bluetooth/ Wi-Fi
Transmission range	10m/ 100m
Message TTL	½ day (12 Hours)
Generated message size	500 KB to 1 MB
Node's movement speed	Min=0.5 km/h Max=1.5 km/h
Routing protocols	Epidemic, Direct Delivery and Max Prop

We use three opportunistic routing protocols in our simulations, they are, Epidemic [16], MaxProp [3] and DirectDelivery [15]. Epidemic is a flooding-based routing protocol. Each node forwards the same copy of the message to the newly-encountered node in the network until the message reaches the destination node. We use Epidemic as the baseline, as it aims to increase the message delivery probability. However, in this type of routing the efficiency of the message delivery process greatly depends upon the buffer size of the nodes. The MaxProp is a probabilistic routing protocol that keeps track of the previous encountered histories to estimate the probability of meeting with the other nodes in the future. For every new encounter, the MaxProp router always checks the greater probability of interactions with the newly-encountered node by higher delivery likelihood values. Finally, in the DirectDelivery routing protocol (commonly known as single-copy routing), a node generates only one copy of the message during transmission (to avoid flooding in the network) and the node waits until this message reaches its final destination.

We ran each simulation 10 times with the different random generator seeds used for the movement model. The performance analysis is done on a computer which has the following configurations of 2 GB RAM, 500 GB hard disk and an Intel core i3 processor @2.27 GHz. We use the commonly-used metrics to evaluate the overall routing performance [5]. They are as follows: (i) Delivery Ratio: The proportion of the delivered messages to the total number of messages created in the network. (ii) Delivery Cost: The total number of medium accesses, normalized by the total number of messages created. (iii) Delivery Delay: The total amount of time to send messages from source to destination.

3.2. Results and Discussions

» **Delivery Ratio**

Figure 1 and Figure 2 shows the message delivery ratio in cases of Bluetooth and Wi-Fi communication scenarios. We see that for the Bluetooth communication scenario (Figure 1) the median message delivery ratio for the Epidemic router is 88.53%, whereas in the case of the DirectDelivery router it decreases to 50.21%. We find that, in the Epidemic router, nodes are replicating multiple copies of the same messages to every newly-encountered node. This improves the message delivery ratio for the Epidemic router.

Figure 1. The message delivery ratio in 'Bluetooth' communication scenario. The MaxProp router gives the better performance by using user's social interactions and collaborations.

But in the case of the DirectDelivery router, a node creates only one copy of the message until it reaches its destination, which reduces its message delivery performance. On the contrary, we find that the median message delivery ratio for the MaxProp router is 93.88%. Because the MaxProp router keeps the previous encountered histories and forwards messages to a newly-encountered node that has a higher probability to get closer to the destination node. Therefore, message delivery performance has been improved greatly in this case. It should also be noted that, we used real-life trace-driven data for our simulations to see the potential effects of users' interactions and social collaborations within the network. We observe that these interactions helped in message forwarding which in turn increased the message delivery ratio in the case of the Maxprop router.

For the Wi-Fi communication scenario (Figure 2) the median message delivery ratio for the Epidemic, DirectDelivery and MaxProp routers are almost the same. They are 98.73%, 95.67% and 98.98% accordingly. As with the results above, we can indicate that message forwarding with a wider communication range used the greater contact probability between the nodes. Which consequently increased the overall message delivery ratio in the network.

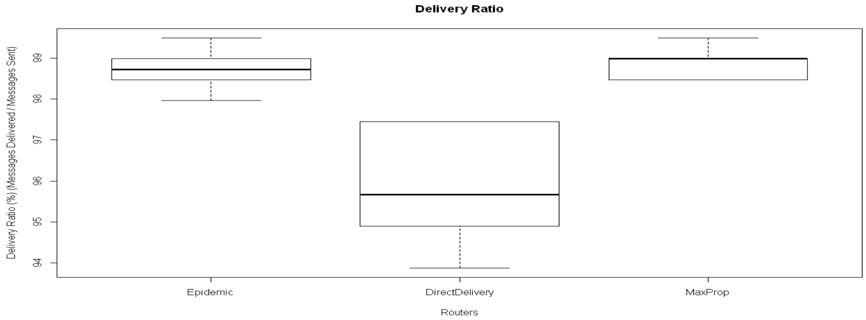

Figure 2. The message delivery ratio in 'Wi-Fi' communication scenario. The median message delivery ratio for all of the routers are almost the same.

» **Delivery Cost**

Figure 3 and Figure 4 shows the message delivery cost in cases of Bluetooth and Wi-Fi communication scenarios. In the case of the Bluetooth communication scenario (Figure 3), the median message delivery cost for the Epidemic router is 40.48 and in the case of the MaxProp router the median delivery cost is 24.16. The Epidemic router generates a large number of messages in the network which in turn increased the message delivery cost. Whereas, the MaxProp router forwarded messages based on the previous encounter histories by reducing the median message delivery cost compared to the Epidemic router. Whereas, the median message delivery cost for the DirectDelivery router is zero as this router only generates a single copy of the message in the network.

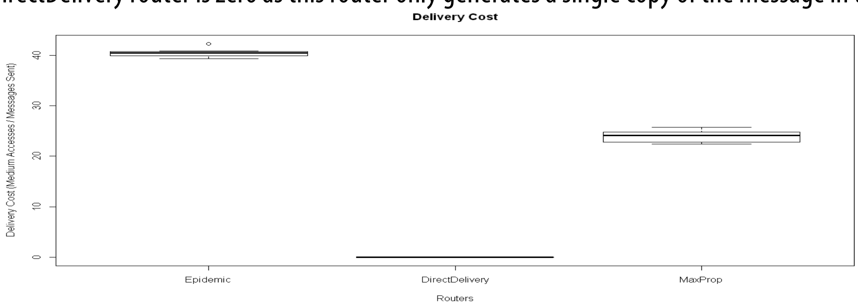

Figure 3. The message delivery cost in 'Bluetooth' communication scenario. The Epidemic router generates a large number of messages which increased the message delivery cost.

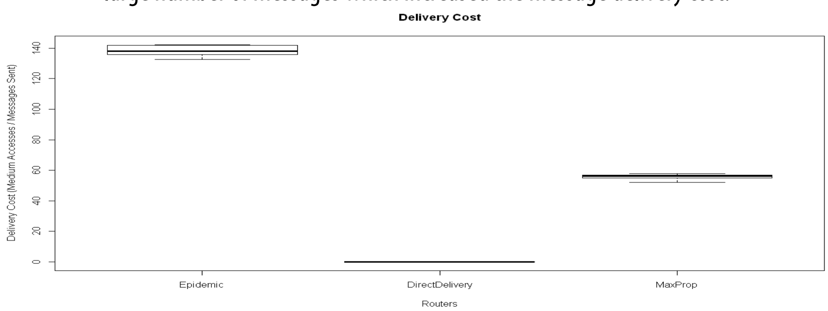

Figure 4. The message delivery cost in 'Wi-Fi' communication scenario. The DirectDelivery router generates a single copy of the message which results zero message delivery cost.

For the Wi-Fi communication scenario (Figure 4), the median message delivery cost for the Epidemic router is 138.03. And for the MaxProp router it is 56.33. We understand that, the Epidemic router replicates a higher amount of messages which increased the message delivery cost compared to the MaxProp router. Same as the Bluetooth scenario above, the median message deliver cost for the DirectDelivery router remained zero.

» **Delivery Delay**

Figure 5 and Figure 6 shows the message delivery delay in cases of Bluetooth and Wi-Fi communication scenarios. The median message delivery delay for the epidemic router, in Bluetooth scenario (Figure 5), is 87.36 minutes, and for the MaxProp router it reduces to 61.47 minutes. By contrast, the median message delivery delay in the case of the DirectDelivery router has increased to 205.5 minutes. We find that due to the node's buffer constraints, the Epidemic router dropped a large amount of messages in the network which resulted in a higher delay. The DirectDelivery router generated only one copy of the message in the network, but it is unpredictable as to when the message would finally reaches its destination. Therefore, searching the entire network has increased the overall message delivery delay for the DirectDelivery router. On the other hand, the user's social collaborations and interactions helped the message delivery performance for the MaxProp router.

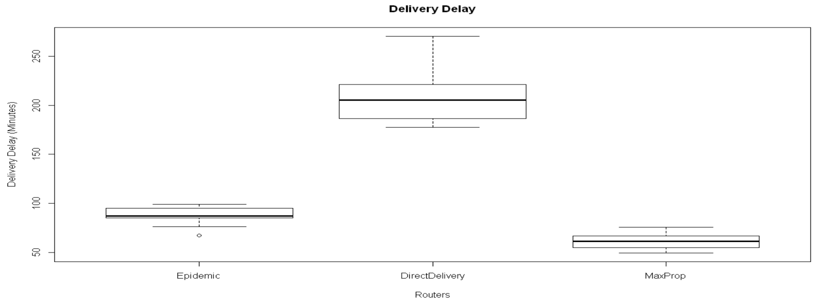

Figure 5. The message delivery delay in 'Bluetooth' communication scenario. The DirectDelivery router generated single copy of the message in the network and for searching the entire network for the destination node has increased the overall message delivery delay.

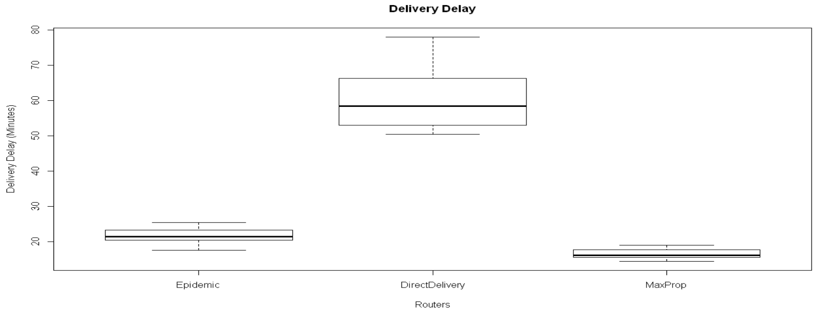

Figure 6. The message delivery delay in 'Wi-Fi' communication scenario. The median message delivery delay is minimum for the MaxProp router as it delivers messages faster by keeping the previous encountered histories.

For the Wi-Fi communication scenario (Figure 6), the median message delivery delay is the minimum for the MaxProp router (16.22 minutes). Whereas, for the Epidemic router it increased to 21.44 minutes. But the median message delivery delay is the maximum for the DirectDelivery router which is 61.23 minutes. Likewise, just as in the Bluetooth scenario, higher amounts of the generated messages increased the overall message delivery delay for the Epidemic router compared to the MaxProp router. But in case of the DirectDelivery router, the message delivery delay is higher due the fact that it generated only one copy of the message. Compared to the Bluetooth scenario the wider communication range (i.e., in Wi-Fi scenario) helped to improve the contact opportunities between the nodes which is why Wi-Fi scenarios gave better performance in the overall message forwarding.

3.3. Lessons Learned

In this section we have summarized our findings based on the discussion in Section 3.2. We have learned that the routing in mobile opportunistic networks is greatly influenced by the wireless communication ranges between the users during message forwarding. Based on these results we note that:

1. It is feasible for message communication using user's mobility patterns and social interactions by using both of the technologies (i.e., Bluetooth and Wi-Fi) but in the case of a shorter communication range, user's social interactions are greatly influenced the message forwarding performance.
2. The MaxProp routing protocol gives the best message delivery performance compared to Epidemic and DirectDelivery routing protocols. Because the MaxProp router keeps the previous encounter histories for the next possible encounter with a node, this ensures a higher probability for delivering the message nearer to its destination.
3. In a wider communication range the overall message delivery ratio is almost similar for all of the routing protocols. We understand that, this is because there is a high probability that the nodes are getting in contact with each other more easily. However, in the case of a mobile opportunistic network, communication in a shorter range is more obvious and therefore users' interactions and willingness for cooperation in message forwarding is important. Perhaps, attractive incentive mechanisms [17] can be enforced in such communications for the users to actively take part in data forwarding.

4. CONCLUSION

In this paper we have discussed the impact of message delivery performance in a mobile opportunistic network when we vary the wireless communication ranges for connecting each other. The two major contributions to this paper are: One, we study a comparison between different opportunistic routing protocols in different wireless communication technologies (i.e., Bluetooth and Wi-Fi) and Two, we use real-life trace-driven simulations to compare and contrast the performance of these routing protocols by exploring user's social collaborations and interactions.

We used three different routing protocols i.e., Epidemic, DirectDelivery and MaxProp for our simulation-based study. We saw that the MaxProp router gives the optimum message delivery performance in the network. Our results also indicated that, if the communication range is short, user's movement patterns are significant and their willingness for cooperating with message forwarding is important to improve the overall message delivery performance. We found that, in a short communication range, users may not have the opportunity to meet many other users in the network. This in turn supports the need for active participation and willingness to share/forward messages by the users in the network.

In future we plan to derive more experiments based on different real-life trace-driven data sets to see significant changes in data forwarding in real world. We also focus on several other areas including the short memory size and battery power, incentive mechanisms, latency related issues as well as efficient bandwidth utilization for message forwarding in mobile opportunistic networks.

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