Implementation of Group-Based Human Movement Model in Opportunistic Network

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Abstract. As an instance of a distributed computing system, opportunistic networks facilitate message dissemination in a store-carry-forward manner. In this setting, the mobile devices are communicating in opportunistic contacts as they move across the network areas. However, the movement of these mobile devices is exclusively reliant on the mobility of the human owner, thereby limiting the probability of contact. The current state of the art typically simulates human movement based on randomness, which is unsuitable for representing how people move in groups. Therefore, this paper proposes an implementation of a group-based human mobility model to simulate device-to-device communication in opportunistic networks. In this model, individuals are able to move as a set within a group and have the ability to join and leave the group dynamically This research built the model in BonnMotion and subsequently implemented it in an opportunistic environment simulator, ONE Simulator. As an evaluation, the proposed model was compared to the random-based model as a benchmark. Subsequently, the impact of the movement model was assessed on two major areas of network performance: message delivery performance and resource utilization, such as nodes' energy consumption. These aspects became the concern of the study since the mobile agents limited resources yet were expected to achieve a high rate of message delivery as well. The simulation results show that the model outperformed the random-based model in terms of the number of successfully delivered messages and average delay. However, the number of message replications and the energy consumption is fairly higher than those of the benchmarks.

Keywords: group-mobility-model; random-walk; opportunistic networks, delivery performance, energy consumption

1. Introduction

The proliferation of computing power and storage size on mobile devices has enabled the realization of mobile distributed networks such as opportunistic networks. In this network, messages are disseminated in a store-carry-forward manner without prior knowledge of the path between sender and receiver [1]. The store-and-carry-forward mechanism in an opportunistic network is depicted in Figure 1. When node S as the source generates message, node S does not yet have an established end-to-end path to the destination node. Next, after relocating to another coordinate, node P finds its neighbour, node Q. Using routing algorithm, Node P will evaluate whether node Q will serve as a good relay for the messages. If node Q is a reliable relay, then the message will be forwarded to it. After receiving the message, node Q is not currently connected to any other nodes besides node S. Thereafter, node Q continues moving until it encounters node R. When node Q meets node R, R's suitability as relay is assessed. If R is considered to be a good relay, then the message will be sent to node R. After node R received the message, then node R moves and eventually meets the destination node. Afterwards, R will deliver the message to its intended recipient.

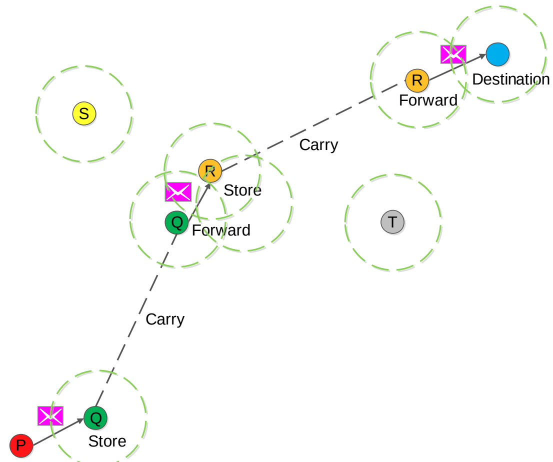

Figure 1. Store-carry-forward mechanism on DTN

This store-carry-forward mechanism is facilitated by mobile devices acting as distributed agents in opportunistic networks. These agents are crucial to the process of message forwarding from source to destination, as they deliberately transport messages across network areas. In addition, mobile devices are owned by humans, so their mobility is solely dependent on their owners. Furthermore, the movement of the agents also determines the frequency of encounters and inherits the ability to send the message to the other node. To create a movement model for agents that mimics actual human behavior, however, is not a simple task. In fact, the proper method for capturing these characteristics is to record the precise coordinates of human movement and observe them over a period. This produces real-world movement datasets, such as the dataset of people's movement during a conference (Haggle Infocomm) [2] and on campus (Reality Mining) [3]. Still, the real-world dataset is the most accurate method, but the data collection process takes a long time and requires active participation from people, resulting in a high cost. This study takes a synthetic modeling approach to the movement model. In contrast to the real-world model, the human synthetic model can be generated with greater flexibility and speed. In addition, the synthetic model is developed by observing human movement behavior, model the behavior and then implementing it in simulation-based settings. Several works have already implemented synthetic-based movement to accurately represent the movement patterns of various objects with defined properties, such as UAV movement modeling and military tactics [4], [5].

In [6], the human synthetic movement model is typically represented using a random-based movement model, such as the random walk movement model. This mobility model assumes that the probability of two nodes meeting is uniform. Despite the fact that this model depicts humans as solitary beings with independent mobility, research [7], [8] indicates that human movement is not entirely random because human characteristics themselves exhibit an implication. Humans tend to move in groups or crowds due to their social nature [9], [10]. Lindorfer and Hossen's studies also confirm that although humans move in groups, they still possess individualistic characteristics, so it is possible that they will occasionally leave the group [11], [12]. This study constructed a group-based movement model to represent the human ability for group participation and holistic movement. In this model, each individual can dynamically join or leave a group. The model is created using BonnMotion[13] and then implemented in ONE Simulator, an opportunistic network environment[14]. The next phase was to assess the network delivery performance and the effect of mobility on nodes' resource utilization, such as energy consumption.

2. Research methods

In this study, several tasks were performed. Firstly, the researchers generated a model of group-based movements using BonnMotion software. Second, following the construction of the movement model, the model was simulated in an opportunistic network environment using ONE Simulator. The next phase was to assess the delivery performance based on the number of delivered messages, the number of message copies on the network, and the average delay. Then, the researchers observed the impact of these movement models on the energy consumption of nodes by measuring the average remaining energy and observing the number of dead nodes within a given time interval.

2.1. Design of movement model

The modeling of movement started with the design of two mobility models: the random walk model and the group movement model. BonnMotion is a Java-based mobility generation tool used to create both models. Figure 2 is a flowchart that outlines the steps of model generation. First, the required input parameters for each model were defined. Second, the model was generated in two separate files: .params and .movement.gz. To simulate the model in ONE Simulator, the model must then be converted to a.one file, a file extension that ONE Simulator recognizes as movement trajectory data.

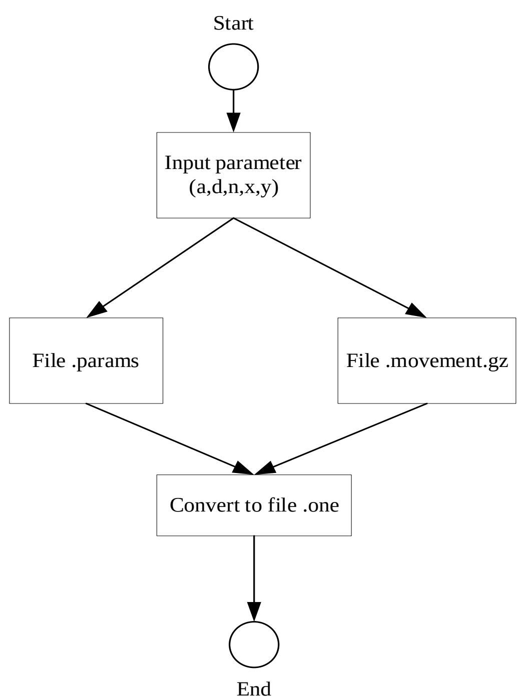

Figure 2. Flowchart of movement model generation

To generate our model, we use the parameters shown in Table 1.

Table 1. Movement model parameters

Parameters	**Group-based movement**	**Random walk movement**
Number of nodes (n)	50	50
Maximum member of a group (a)	5	-
World size (x,y)	500 m x 500 m	500 m x 500 m
Simulation time (d)	21600 s	21600 s

After creating and converting both movement models to the.one file format, the file was then imported as input into the ONE simulator environment. Figures 3 and 4 depict the visualization of movement models.

As depicted in Figure 3, the group-based movement model was simulated using 50 nodes designated p0 through p49. These nodes were initially divided into a group with no more than five members. Each group of nodes always traveled together and had a chosen leader. The group's movement direction was determined by the leader's mobility. In other words, a group member always traveled in the same direction as the group leader. In order to add the ability for nodes to join and leave groups dynamically, this group-based model enabled nodes that encountered another group while in motion to immediately leave their current group and join the encountered group. As a result, this node's mobility would then follow the leader's movement in the newly joined group. Figure 3 shows that the number of members in each group is different and vary over time.

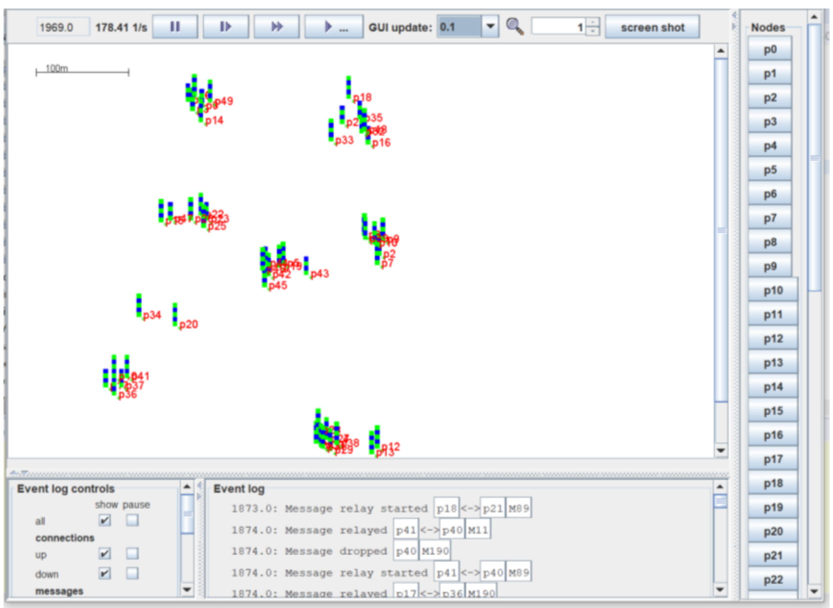

Figure 3. Group-based movement visualization

In comparison, 50 nodes were also modelled in random walk-based movement. In this movement model, each node could move independently, as opposed to the group movement model where the direction of movement of members must follow the movement of the group leader. Figure 4 is a visual representation of the random walk motion.

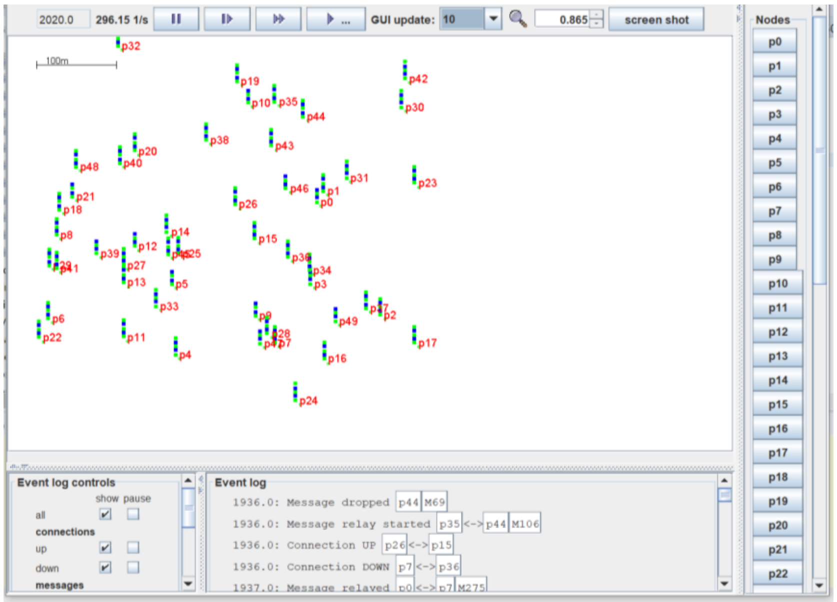

Figure 4. Random walk movement visualization

2.2. Simulation design

2.2.1. Simulation parameters

The two movement models (random walk and group movement) then were simulated in ONE Simulator, an opportunistic network simulation environment. In the simulation, the parameters shown in Table 2 were specified. This simulation applies Epidemic, a flooding-based routing protocol, to facilitate the process of message dissemination [15]. Moreover, in this simulation, resource utilization measurement was represented by nodes' energy consumption. The energy model was assumed that message transmission required more energy than neighbor discovery (scan energy).

Table 2. Simulation parameters

Parameters	**Group-based movement**	**Random-based movement**
Number of nodes	50	50
World size	500 m x 500 m	500 m x 500 m
Simulation time	21600 s	21600 s
Routing protocol	Epidemic	Epidemic
Buffer size	5 M	5 M
Initial energy	10000	10000
Transmit energy	2	2
Scan energy	0,05	0,05

In addition to specifying the simulation parameters, two simulation scenarios were conducted to evaluate the models: scenario 1 and scenario 2.

2.2.1.1. Scenario 1 (Measure delivery performance)

In scenario 1, the performance of message delivery was evaluated by examining reports containing information about the number of delivered messages, the number of message copies in the network, and the average delay. Good delivery performance was achieved when the number of successfully delivered messages was high, while the number of message copies and average delay were low.

2.2.1.2. Scenario 2 (Measure resource utilization)

In scenario 2, the utilization of resources was studied. In this case, the energy consumption of a node was used to represent resource utilization. Then, an examination was conducted to see whether the group-based movement model led to higher node energy consumption than the random-based model. This evaluation was crucial since energy was a constrained factor in opportunistic network. In this scenario, the monitoring was conducted by looking at the number of dead nodes in each time interval throughout the simulation, as well as the average amount of energy remaining at the end of the simulation.

3. Results and Discussions

3.1. Result of simulation scenario 1

The simulation result depicted in Figure 5 indicates that group-based movement results in a greater number of delivered messages. The reason was that group formation accelerated message distribution, particularly among group members as they traveled together, allowing for message to transfer over a relatively long period of time. The ability to join and leave a group also increased the probability of a changing-group node in disseminating messages to a newly joined group, thereby accelerating the massive message spread and allowing more messages to reach their destination.

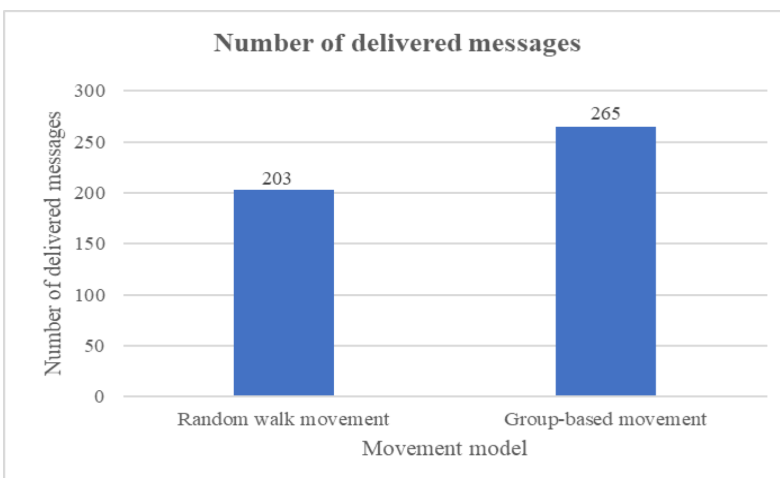

Figure 5. The number of delivered messages

In addition, group-based movement led to faster message dissemination than random-based models. This result is depicted in Figure 6, revealing that group-based movement resulted in a lower average delay. This indicated that messages were delivered to their respective destinations more quickly due to the group-based model's tightly connected nodes. Additionally, the nodes in each group were able to exchange messages within their respective group and eventually forwarded them to another group, leading to increased variety of messages in nodes' buffer. Later, these diverse messages increased the probability of message forwarding to dozens other nodes.

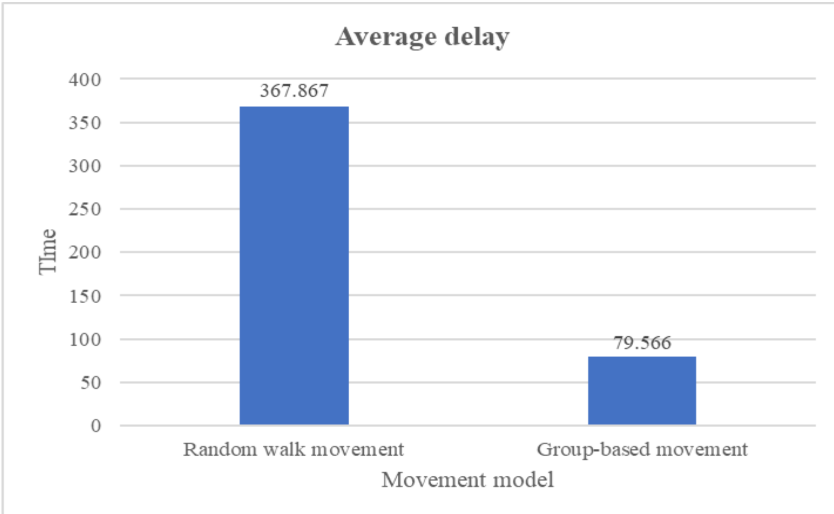

Figure 6. The average delay

The massive exchange of messages between group members during group movement, on the other hand, generated a large number of message copies. Figure 7 demonstrates that group-based movement resulted from a greater number of message copies compared to the counterpart model.

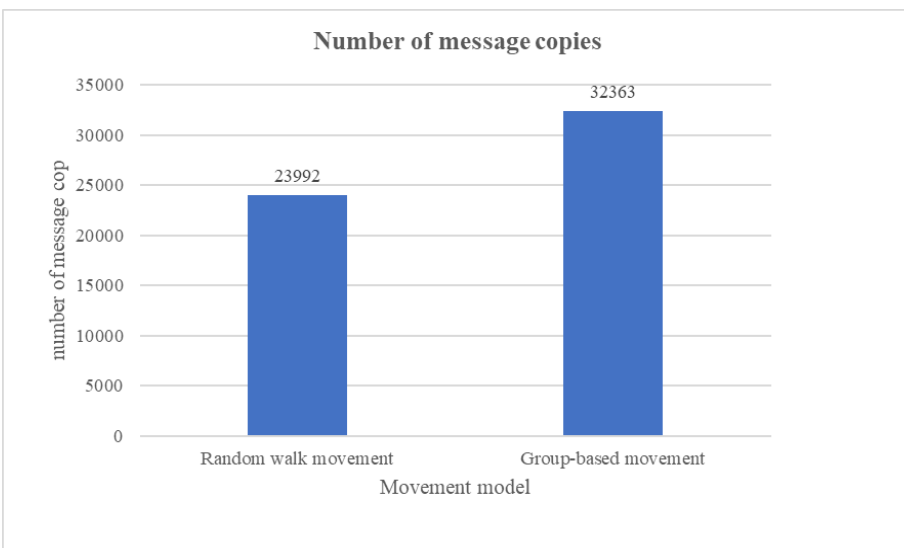

Figure 7. The number of messages copies.

3.2. Results of simulation scenario 2

In scenario 2, the group-based movement model was evaluated to determine the energy consumption of nodes represented by the number of dead nodes (energy level is zero or below zero) and the average remaining energy of all nodes. Figure 8 and Figure 9 illustrate the simulation results. As shown in Figure 8, the number of dead nodes in group-based movement increased significantly over time; by the end of the simulation, only 11 nodes had successfully maintained energy levels above 0. This was due to the fact that in group-based movements, messages were rapidly and extensively forwarded within and outside the group.

In line with the definition of this research energy model, transmitting a message required more energy than other activities. The message transmission in this instance was enormous, leading to the rapid energy depletion of nodes. In contrast, in the random-based model, the probability of encountering nodes was relatively the same. This enabled nodes to sustain energy for a longer duration.

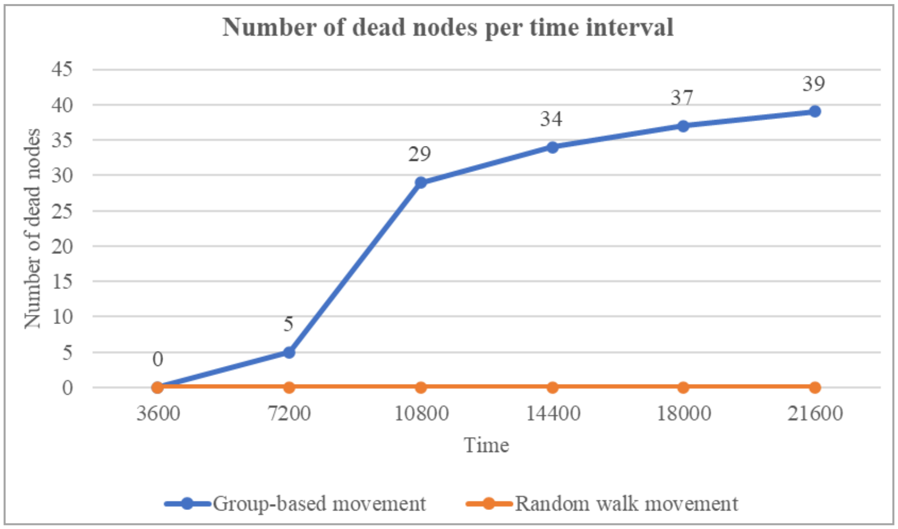

Figure 8. Number of dead nodes per time interval

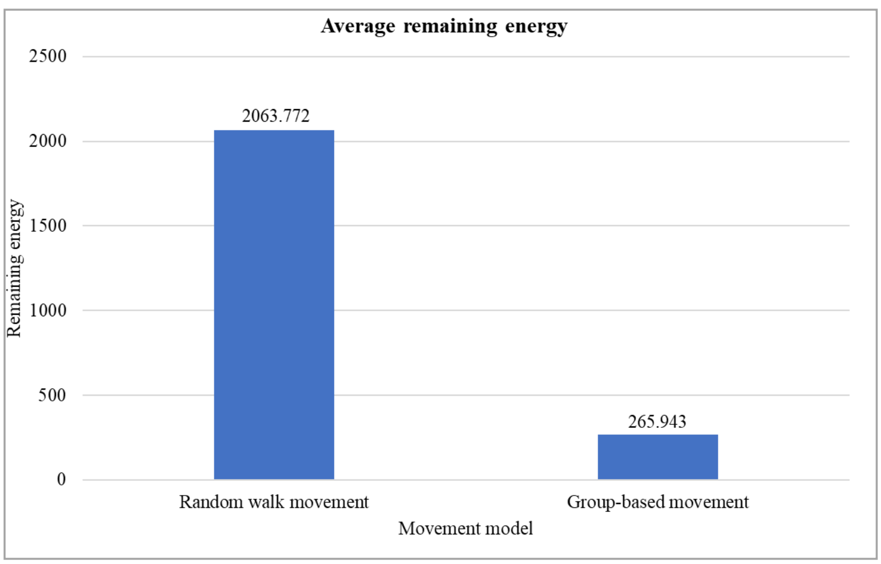

Figure 9. Average remaining energy

In addition, in Figure 9, the average remaining energy in the group-based model was significantly lower than in the random-based model. This was due to the fact that that in group movement, messages spread at a faster rate. Consequently, the transmission of messages consumed a considerable amount of energy. In contrast, in random walk movement, the meeting probability of each node was equal, and each node would eventually encounter a comparable number of other nodes. This resulted in a gradual decrease in energy consumption because the transmission process did not occur too frequently, ultimately conserving the energy of nodes. These energy savings are further illustrated in Figure 9, where the average remaining energy for random-based movement is significantly higher than that of group-based movement.

4. Conclusions

In this study, it was presented the group-based movement model that reflected the characteristics of human group movement as social beings who dynamically join and leave a certain group. Then, this phenomenon was subsequently simulated in an opportunistic network environment. The simulation results showed that, regarding message delivery performances, the group-based movement yielded a good performance reflected by a higher number of delivered messages and lower average delay compared to the random-based model. However, the number of message copies was enormous. In terms of resource utilization, I was found that nodes in group-based movement consumed more energy than those of random-based.

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