Turkish Journal of Electrical Engineering & Computer Sciences

http://journals.tubitak.gov.tr/elektrik/

Research Article

Turk J Elec Eng & Comp Sci
(2020) 28: 708 – 726
© TÜBİTAK
doi:10.3906/elk-1904-102

Novel random models of entity mobility models and performance analysis of random entity mobility models

Metin BİLGİN*
Department of Computer Engineering, Faculty of Engineering, Bursa Uludağ University, Bursa, Turkey

Received: 12.04.2019 • **Accepted/Published Online:** 23.09.2019 • **Final Version:** 28.03.2020

Abstract: It has become possible to collect data from geographically large areas with smart devices that are prevalently used today. Sensors that are integrated into smart devices make it possible for these devices to receive and transmit data wirelessly. The most important problem of this model that is known as mobile crowd sensing and that allows inferences on the data obtained from its users is lack of data. The main reason for this problem is the lack of sufficient usage of the sensors on devices by the user. To increase the amount of data collected, while users may be incentivized in various ways, the amount and accuracy of the collected data may be increased by developing random entity mobility models (REMMs). In this study, two new models (random point and random journey) were proposed as alternatives to existing REMMs. In the experiment environment that was created to measure the performances of the proposed models, their performances were compared to those that are currently used prevalently (random waypoint (RWP), random walk (RW), and random direction (RD)). In the experiment environment, the performances were compared in terms of three different metrics (visiting rates of nodes, rates of reaching the basis, and the number of messages they carried to the basis). The greatest increase in differently sized areas and at different numbers of nodes in the RP model in terms of rates of reaching the basis was 2.6% compared to RWP, 7% compared to RW, and 46.34% compared to RD, while these values for the number of nodes that were visited were 3% compared to RWP, 1.5% compared to RW, and 17.67% compared to RD. In the same conditions in terms of the metric on the number of messages, the model collected 1465.4, 2933.46, and 7260.12 more messages than those in respectively RWP, RW, and RD. The greatest increase in differently sized areas and at different numbers of nodes in the RJ model in terms of reaching the basis was 1% compared to RWP, 3.5% compared to RW, and 25% compared to RD, while these values for the number of nodes that were visited were 0.75% compared to RWP, 2% compared to RW, and 21.4% compared to RD. In the same conditions in terms of the metric on the number of messages, the model collected 1109.56, 1534.26, and 4488.5 more messages than those in RWP, RW, and RD, respectively.

Key words: Random entity mobility model, modeling and simulation, analysis of mobile networks, mobile crowd sensing, sensor, connectivity, mobile sensor networks

1. Introduction

Nowadays, technology is a part of both daily life and work life. Media and network technologies such as the Internet, social networks, and 3G/4G networks constitute a significant part of our lives. These developments in technology have led to the emergence of new study areas like the Internet of Things (IoT) and Big Data. Using IoT, it has become possible to connect the cyber and physical objects of numerous sensor devices in our living areas [1, 2]. Mobile users on wireless sensor networks have become a significant source of data sensing

---

*Correspondence: metinbilgin@uludag.edu.tr

This work is licensed under a Creative Commons Attribution 4.0 International License.

with the prevalence and development of mobile devices today [3]. With the novel way of sensing called mobile crowd sensing (MCS); the data produced by smart phones, tablets, and wearables have started to be used as geo-crowdsourcing. Table 1 shows information on some devices with embedded sensors [4]. In studies so far, geographical spatial information collected from these sensors has been shared with other users [5, 6]. In fact, MCS is presented as a paradigm consisting of IoT and voluntary individuals. The existing IoT services in the world are being designed for development and discovery of new-generation, smart networks. With this design, a new model with things–things, things–human, and human–human connections is proposed.

Studies on MCS are usually related to collection of data from personal and mobile devices [7]. The difference of MCS from conventional sensor networks is that it is user-oriented. This way, users who had been in a passive position so far have started to play a more active role with MCS.

Burkel et al. [8] proposed the MCS in 2006 for the first time. MCS applications may involve participatory or opportunistic sensing. People actively participate in participatory sensing processes and decide the details of the data collection process, while they passively participate in opportunistic sensing process. Nowadays, the number of developed applications has been gradually increasing in mobile crowd sensing.

Table 1. Mobile devices equipped with sensors.

Sensor	Iphone 8	Samsung S8	Garmin vivoactive 3	Tesla model X
GPS	+	+	+	+
Accelerometer	+	+	+	-
Barometer	+	+	+	-
Compass	-	+	+	-
Gyro	+	+	-	-
Proximity	+	+	-	+
Ambient light	+	+	-	+
Fingerprint	+	+	-	-
Thermometer	-	-	+	-
Heart rate	-	+	+	-
Iris	-	+	-	-
Hall	-	+	-	-
Camera	+	+	-	+
Microphone	+	+	-	+
Radar	-	-	-	+

Several different REMMs have been used in MCS implementations so far. These practices have rather been applied practices, and there are no studies that revealed the pros and cons of existing methods in comparison to each other. The first point of motivation for this study was to reveal the performances of the currently most frequently used REMM in terms of three different metrics that we determined. Although this part of the study has some novelty in terms of interpretation of the results that are obtained, it does not have many contribution on the innovative aspect as it does not propose a new method. This is why two new REMMs were proposed by examining the existing methods. The proposed methods were designed and aimed to visit more nodes in comparison to the existing methods, carry more nodes to BS, and increase the number of messages that are received. In the process of the study, the performances of these two methods were measured and compared with the existing methods.

The remainder of this paper is organized as follows. Section 2 presents a review of the related MCS and Section 3 provides current REMMs and two new models proposed. Section 4 presents the theoretical evaluation and Section 5 presents the experiment evaluation. Section 6 presents results and discussion. Section 7 provides the conclusions and suggestions for future work.

2. Related works

In this section, we present related work for MCS. Ra et al. [9] developed a new framework for crowd sensing that is named Medusa. Medusa has ensured high-level abstractions for crowd-sensing missions and their execution among smart phones and a cluster on the cloud. Carreras et al. [10] developed a new framework for crowd-sensing missions that is named Matador. This framework includes the design and implementation of the platform. Zaslavsky et al. [11] presented mobile data stream mining. This study includes mobile data collection and run-time processing. Also this significant approach has been a component of mobile runtime analytics. Guo et al. [12] introduced the literary history of MCS and its original topics. Ma et al. [13] examined the opportunistic features of human mobility from the perspectives of both sensing and transmission. Zhang et al. [14] proposed the four-stage life cycle for MCS. It used 4W1H (i.e. what, when, where, who, and how) to solve the investigated problems in the MCS domain. Pournaja et al. [15] examined the issue of spatial mission appointment in crowd sensing when the contributor uses spatial cloaking to black out their locations. Wen et al. [16] proposed an incentive mechanism based on a quality-driven auction. The operation is specifically for the MCS system, where the worker is paid off based on the quality of sensed data in place of working time, as accepted in the literature. Aly et al. [17] proposed a system that leverages standard cell-phone sensors in a crowd sensing approach to automatically prosper digital maps with different road semantics like tunnels, bumps, bridges, footbridges, crosswalks, road capacity, etc.. Zhang et al. [18] examined various strategies that are suggested in the literature to provide motivations for stimulating users to join the mobile crowd sensing applications. Guo et al. [19] defined the unique features and new application areas of MCS and Computing MCS (MCSC) and suggested a reference framework for building human-in-the-loop MCSC systems. They concluded with the restrictions, open topics, and further investigation opportunities of MCSC. Hu et al. [20] suggested SmartRoad, a crowd-sourced road-sensing system that detects and identifies traffic regulators, traffic lights, and stop signs. Bilgin and Şentürk [4] proposed two different data validation methods for random waypoint. These methods that were based on means and frequencies were compared in terms of the nodes that were connected to and the numbers of messages in differently sized areas and at different numbers of nodes. As a result, the mean-based approach was observed to reach higher rates for RWP. Althunibat et al. [21] calibrated the random waypoint model to measure the mean bit error that occurs in space modulation techniques. Nawaz et al. [22] used REMMs to determine the communication statuses of unmanned aerial vehicles in different environmental conditions. Guillen-Perez and Cano [23] examined REMMs that are currently used in terms of mobility, positioning, and distribution models for flying ad hoc networks (FANET). Petit et al. [24] conducted an experiment where they examined the status of the RW method in general stochastic temporal networks that allow its permanent interactions. They investigated the situations provided by the RW method based on the structure of the network that was created. Wu et al. [25] defined constant position entropy and orbital entropy based on the gravity mobility model to measure the level of orbit preservation. Possible orbit schemas were found for the two parameters that were obtained as a result of their study. Hussaini et al. [26] developed an implementation based on the RWP and RW methods to measure motion-centered effects and prove the presence of monotony to support all types of mobility support approach or plan of the model they proposed. Hussaini et al. [27] developed an RWP-based application to transmit the new prefix or position of the mobile producer. Yoshimura et al. [28] studied modeling of the movements of people who visited a large museum with the RW method. As a result of their study, they demonstrated that the model that was formed on short-term visitors was weaker than the model created with individuals who stayed in the museum for longer times. Samouylov et al. [29] utilized an RW model to be able to evaluate service quality in 5G wireless networks.

It may be seen that the available studies in the literature are rather focused on applied practices. They generally consist of the application of the existing methods on different problems. The purpose of our study is to derive the characteristics of the existing REMMs in differently sized areas and at different numbers of nodes. This way, new models could be proposed independently of the movement styles of the existing models. Additionally, with the two newly proposed methods, it was aimed to increase parameters that are of importance for mobile data collectors like the number of nodes that are connected, the number of nodes that are visited, and the number of messages that are collected.

3. Materials and methods

Information was provided in this section about three random models, i.e. random waypoint (RWP), random walk (RW), and RD, which are commonly used and also regarded as the foundation in this study. In the figures, the blue node expresses the mobile node (sensor), the red node expresses the node, and the black node expresses base station.

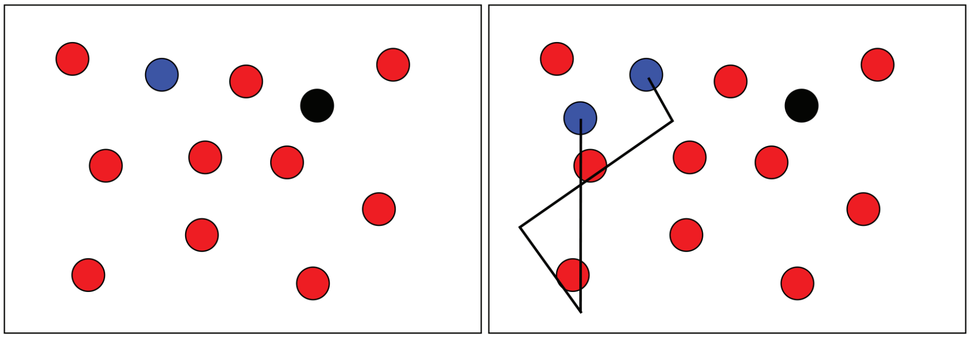
3.1. Random waypoint (RWP)

Johnson and Maltz [30] proposed the Random Waypoint for the first time, and it was used by lots of researchers for wireless network systems' performance [31, 32]. Mobil node designs the movement to random (x_0, y_0) coordinate at random speed with definition range (between V_{min} and V_{max}). When the definition coordinate is reached, mobile node by algorithm moves to random new coordinate at random speed with definition range. This is the most commonly used model among mobility models [30, 32, 33].

Ko and Vaidya's study [34] is an example of a simplified version. The random waypoint is the most widely used model. The RWP is presented in Figure 1.

3.2. Random walk (RW)

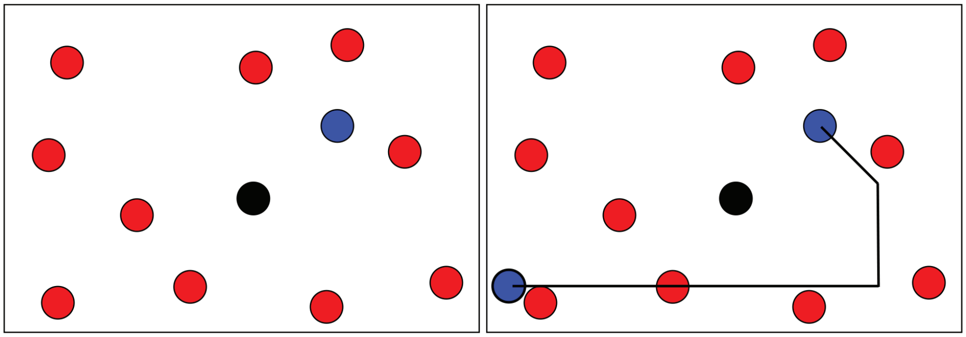
Einstein mathematically explained this model in 1926 for the first time [35]. It was developed for imitation of the unpredictable and irregular movement of lots of entities in nature [36]. In this model, the mobile node moves for a while in random a direction (between 0 and 2π) at a random speed (between $Vmin$ and $Vmax$). The direction, speed, and time are randomly redefined and then the visiting continues. The mobile node continues visiting until the initially defined time. There can be more than one mobile nodes. The RW model is referred to as the Browian motion in some sources and it is commonly used in mobility models [37–40]. In use, this model had sometimes been simplified. For example, a simplified RW was defined by Basagniet et al. [41]; each mobile node had the same speed. The RW is a very simple RWP model and is presented in Figure 2.



(a) Random Initial State for RWP

(b) The result of 10-seconds

Figure 1. Random waypoint (RWP).



(a) Random Initial State for RW

(b) The result of 10-seconds

Figure 2. Random walk (RW).

3.3. Random direction (RD)

The random direction model is similar to the RW model. The difference between them is that RD moves in a random direction (between 0 and 2π) at a defined random range (between V_{min} and V_{max}) speed until the defined area's border is reached. Random direction and speed are redefined when the defined area's border is reached and then the visiting continues and RD is a type of RW [42]. The RD mobility model was proposed to overcome the problems of the RWP model, in order to distribute more uniformly the points in the simulation area. The RD is presented in Figure 3.

3.4. Proposed algorithms

Two new and different models recommended as alternatives to the existing REMMs will be introduced in this section. The notations for the model algorithms are given in Table 2.

3.4.1. Random point (RP)

The proposed RP model was inspired by the RWP model. While a mobile node operates at a random speed (between Vmin and Vmax) towards a random coordinate (x_0,y_0) in this model, it diverges from RWP in the sense of the path it followed. The mobile node completes the first stage of the model by trying to equalize the random x or y coordinate to reach the randomly determined (x_0,y_0) coordinate. Afterwards, if the x

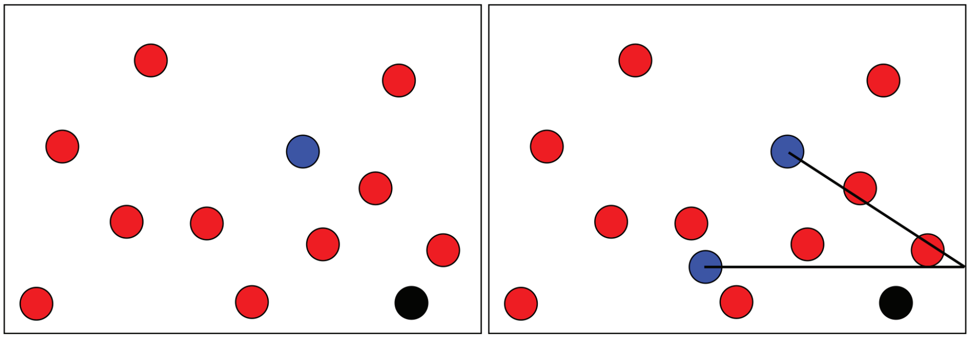

(a) Random Initial State for RD **(b)** The result of 10-seconds

Figure 3. Random direction (RD).

Table 2. Notations Used in the Algorithms.

Notation	Description	Value
length	Edge Length	150-200-250 (pixel)
mobile.X-mobile.Y	Coordinate of Mobile Node	Randomize (0-Length)
direction	Direction of movement	0-1 for RP, 0-7 for RJ
pixel	Distance Travel	MinPixel≤ pixel≤MaxPixel
dist	Distance	distMin<dist<distMax (Only RJ)
remaing_pixel	Remaining pixels to target	(Only RP)
final.X-final.Y	Coordinate of Target	Randomize (0-Length)
MinPixel-MaxPixel	Value of Pixel	0<Manual<Length
distMin-distMax	Value of Distance	0<Manual<Length (Only RJ)
loop	Movement	dist/pixel (Only RJ)

coordinates are equalized, the y coordinates are attempted to be equalized and vice versa. A random point is attempted to be accessed with a style of movement resembling an L, like a knight in a game of chess. The RP is presented in Figure 4 and Algorithm 1.

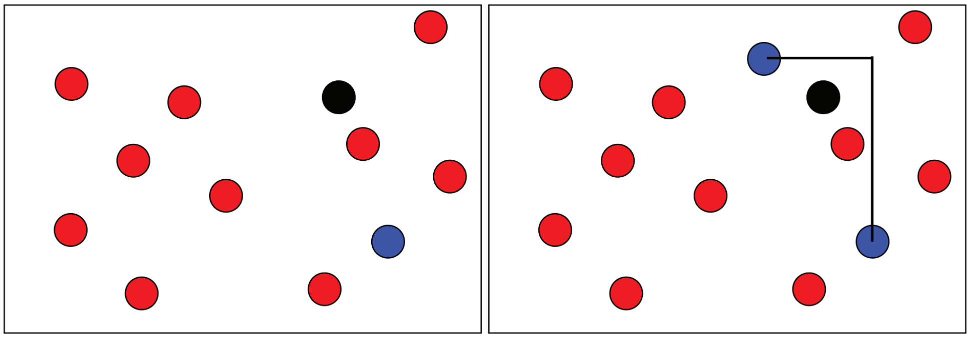

(a) Random Initial State for RP **(b)** The result of 10-seconds

Figure 4. Random point (RP).

Algorithm 1: Random Point Model (Traversal)

```
initialization
final.X,final.Y=Randomize(0,length)
pixel=Randomize(MinPixel,MaxPixel)
direction=Randomize(0,1)
if ($mobile.X < final.X and\ mobile.Y > final.Y$) then
    switch the value of direction do
        case 0 do
            remaing_pixel = (final.X - mobile.X) % pixel
            while mobile.X<=final.X do
                mobile.X+=pixel
            end
            mobile.Y-=remaing_pixel
            while mobile.Y>=final.Y do
                mobile.Y-=pixel
            end
            mobile.X=final.X
            mobile.Y=final.Y
            break
        end
        case 1 do
            remaing_pixel = (mobile.Y – final.Y) % pixel
            while mobile.Y>=final.Y do
                mobile.Y-=pixel
            end
            mobile.X-=remaing_pixel
            while mobile.X<=final.X do
                mobile.X+=pixel
            end
            mobile.X=final.X
            mobile.Y=final.Y
            break;
        end
    end
end
if mobile.X<final.X and mobile-.Y<final.Y then
    (...)
end
if mobile.X>final.X and mobile.Y<final.Y then
    (...)
end
if mobile.X>final.X and mobile.Y>final.Y then
    (...)
end
if mobile.X=final.X then
    (...)
end
if mobile.Y=final.Y then
    (...)
end
```

3.4.2. Random Journey (RJ)

The RJ model is a model developed based on the RW model. In this model, the mobile node moves up to a randomly specified pixel measurement in a random direction (0-2π). When reaching the relevant point, the duration of the navigation simulation continues until completion up to a random the number of pixels for a random, different direction. The RJ is presented in Figure 5 and Algorithm 2.

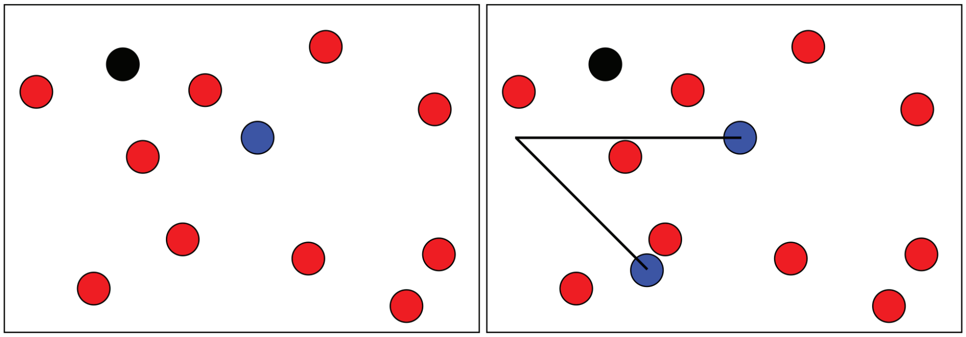

(a) Random Initial State for RJ **(b)** The Result of 10-seconds

Figure 5. Random journey (RJ).

4. Theoretical evaluation

In this section, the hypotheses of the models we proposed are presented. While forming these hypotheses, the movement styles of the RWP, RW and RD models that are currently used were investigated in detailed, and new model propositions were presented by intervening with the points that could be improved.

The two models that we propose here were developed by inspiration from the existing RP and RWP models. The RWP model goes in a randomly determined direction at a randomly determined speed. A motion that is carried out in a randomly determined direction may be expressed with the probability of encountering nodes in one single direction. However, the first model here was developed with the hypothesis that reaching a determined target point by following an L-shaped path like the knight piece in chess, and therefore by moving in two different directions, increases the probability of visiting more nodes and possibly encountering the BS node more frequently.

RJ, which is the second model we propose, was developed with inspiration from the RW model. It was developed by thinking that, in contrast to RW, going towards a random direction at a random distance instead of for a random time would provide benefits in terms of better usage of time.

As the RD model among the examined models is similar to the RW model and as moving towards the boundaries of the determined area in the determined direction increases the number of unnecessary steps and would create a negative effect on the parameters to be examined, no improvements were considered for this model for this time.

Both models that were created were expected to visit model nodes, reach the BS node more frequently and collect more messages in comparison to the existing models that were used for comparison.

5. Experimental evaluation

The proposed network model is referred to as a crowd-assisted network (CaNET) and the mobile devices in the network signify corresponding participants. A sample CaNET can be found in Figure 6 [4]. This section

Algorithm 2: Random Journey Model (Traversal)

```
initialization
direction = Radnomize(0, 7)
pixel=Randomize(MinPixel,MaxPixel)
dist =Randomize(distMin,distMax)
int pixel_J= 0
int loop = dist / pixel
for (int j = 0; j < loop; j++) do
    if (direction==0) then
        while mobile.Y-pixel> 0 and pixel_J<=dist do
            mobile.Y = mobile.Y - pixel;
            pixel_J += pixel;
        end
    end
    if (direction==1) then
        (...)
    end
    if (direction==2) then
        (...)
    end
    if (direction==3) then
        (...)
    end
    if (direction==4) then
        (...)
    end
    if (direction==5) then
        (...)
    end
    if (direction==6) then
        (...)
    end
    if (direction==7) then
        (...)
    end
end
```

describes the experimental setup and defines performance metrics initially. Then, for each performance metric, the results are demonstrated and discussed.

5.1. Experiment setup

We have created a simulation environment with C# programming language in Visual Studio 2015. We have researched five different mobility models in different areas in terms of different metrics (message count, connectivity etc.) by simulation environment. The parameters used for simulation are shown in Table 3. For the five different REMMs, 50 iterations were attempted, and the accuracy of the results was attempted to be increased based on the averages of the acquired results. A symbolic representation of the created experiment area is given in Figure 7.

Table 3. Parameters used in the experiment.

Parameter	Value
Area (pixel)	150x150-200x200-250x250
Node diameter (pixel)	Manual (20)
Simulation duration (second)	Manual (250)
Speed (pixel/second)	Manual (Min. 20- Max. 25)
Base location	Random
Number of mobile nodes	1
Distance (pixel-only RJ)	Manual (50-100)

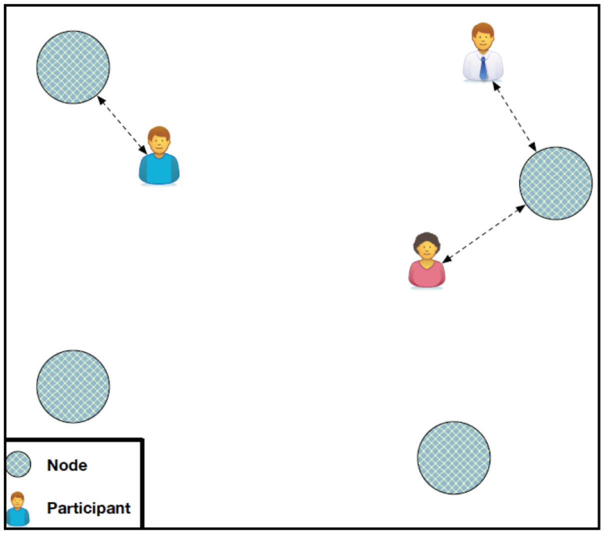


Figure 6. A sensor network with four disconnected nodes [4].

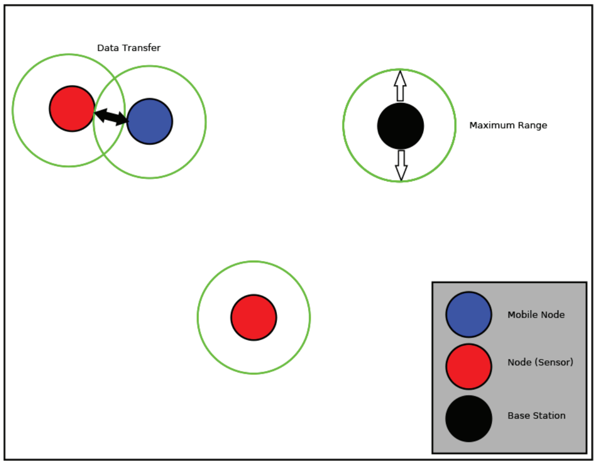


Figure 7. Environment of experiment.

It has been recognized for the experiment setting that:

- All nodes possess memory with limitless capacity.
- Each node gathers 1 message at every 1 millisecond.
- Message transfer is active with a mobile node entering a node's coverage area, and messages emerging from the coverage area until the final period are transferred to BS. The messages collected on the node when there is no connection and therefore not previously transferred are transferred when the same node is revisited.
- The iteration period was 250 second and was calculated as 50 iterations.

5.2. Performance metrics

Three metrics were used to compare the performances of the methods proposed in this study with the other three methods we used as foundation. These metrics are explained in this section.

- The number of visited nodes: This metric indicates the number of nodes visited by at least one participant. This metric implies coverage if participants provide long-range communication.
- The number of connected nodes: If the participants employ only short-range communication methods then the participants should also visit the BS in order to forward the collected data. This metric implies coverage when participants provide short-range communication.
- Message count: This metric signifies the total number of messages delivered to the BS.

6. Results and discussion

Five different proposed REM models, of which two are new, were used in the present study. The numbers of fields and nodes were changed for these five different models and their performances were evaluated. The results for previous studies are seen in Tables 4–6, and the graphical representations are seen in Figures 8–10. The connection Figure 8 formed because of field and node changes demonstrates the numbers of visited nodes. The connection Figure 9 formed because of field and node changes demonstrates the number of established nodes. Figure 10 shows the number of messages formed because of field and node changes.

Table 4. The results for 150x150 area.

Count of node	Connected nodes(%)	Visited nodes(%)	Message count	Model
4	99	99.5	7788.78	RD
	96.50	98.5	7755.62	RW
	100	100	8916.24	RWP
	100	100	8732.86	RP
	100	100	8331.42	RJ
6	98	100	10793.24	RD
	99.67	100	11499.8	RW
	100	100	13310.54	RWP
	100	100	13192.02	RP
	100	100	12273.48	RJ
8	99.75	99.75	15790.88	RD
	97.75	99.50	15269.92	RW
	99	99.25	15494.10	RWP
	100	100	16959.50	RP
	100	100	16603.66	RJ
10	98.60	99	19136.02	RD
	97.20	99.20	18747.46	RW
	100	100	21663.94	RWP
	100	100	21680.92	RP
	100	100	20281.72	RJ

When the results obtained based on the change in the number of nodes in a 150x150 field are examined in Table 4, the number of messages, one of the performance metrics measured based on the increase in the number of nodes, increased while the other two metrics produced similar results. It is expected that the increase in the number of nodes for which data was collected would increase the number of collected messages. The study

Table 5. The results for 200x200 area.

Count of node	Connected nodes(%)	Visited nodes(%)	Message count	Model
4	77	88.50	4602.88	RD
	93	98	6296.28	RW
	98	100	7597.66	RWP
	99.50	100	7431	RP
	91	97.50	6295.90	RJ
6	74	89.33	6505.42	RD
	95	98.67	10353.60	RW
	97.67	98.33	10599.36	RWP
	99.67	100	11130.66	RP
	94.33	97.33	9748.62	RJ
8	84.25	91	10721.78	RD
	97.75	98.25	14584.90	RW
	99	99.25	14909.94	RWP
	99	99.50	14631.40	RP
	97.75	98.25	13695.24	RJ
10	81.60	92	11782.78	RD
	94.40	98.60	17400.42	RW
	95.80	99.40	17224.82	RWP
	98.40	99.40	18141.92	RP
	94.80	97.80	16271.28	RJ

succeeded in producing better results than the others in the two models recommended in the connected nodes and visited nodes article. While RP produced values below but close to RWP in terms of the number of messages for 4–6 nodes, it succeeded in reaching the best values for 8–10 nodes. RJ similarly obtained better results than the other methods for 8–10 nodes and generally succeeded in being among the top three in terms of the number of messages. RD and RW produced similar results for the three metrics.

As can be seen in Table 5, the RP model succeeded in producing better results for the connected nodes and visited nodes metrics. The lower values compared with Table 4 is proof that there is an inverse relationship between alanine growth and these two metrics, and this is an expected situation. The RJ model succeeded in producing close results, although it fell behind RP and RWP. When studied in terms of the number of messages, the RP model produced the best performance of the other situations except for four nodes. RJ, however, fell behind the other methods, although it produced values close to the other models as the number of nodes increased. RD yielded the poorest performance in all the performance metrics.

As the values given in Table 6 suggest, the RP model in the connected node and visited node values succeeded in producing better results compared with the other methods. The RJ method succeeded in passing RD, although it fell behind the other methods for these two metrics. RWP succeeded in producing the best results in terms of the number of messages. The RP model fell somewhat short although it produced values close to RWP. The changes that the metrics exhibited compared with the number of nodes for all three experiment settings were calculated approximately and are given in Table 7.

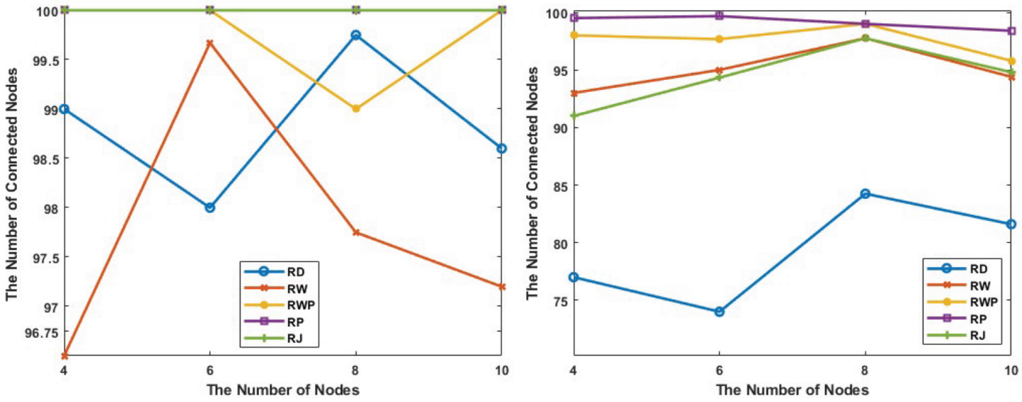
The greatest change in the connected node and visited node metrics were seen in the RD model as the field grew larger and the number of nodes increased. All methods similarly exhibited a positive increase with a

Table 6. The results for 250x250 area.

Count of node	Connected nodes(%)	Visited nodes(%)	Message count	Model
4	56	83	3096.20	RD
	82	96	5440.84	RW
	88.50	97	5542.62	RWP
	89	97	4993.28	RP
	81	92.50	4609.32	RJ
6	46.33	76	3578.42	RD
	85.67	96.67	7913.72	RW
	91	96.33	8894.02	RWP
	92.67	96.67	8286.40	RP
	79.33	93.67	6244.408	RJ
8	50	79	4936.92	RD
	91.25	97.50	11617.96	RW
	89.75	94.75	11889.18	RWP
	92	97.75	11277.24	RP
	68.75	90.25	7992.60	RJ
10	46.80	75.40	5852.50	RD
	88.80	96.20	14087.02	RW
	87.60	95	14414.74	RWP
	90	96.80	13112.62	RP
	67	92.40	8713.28	RJ

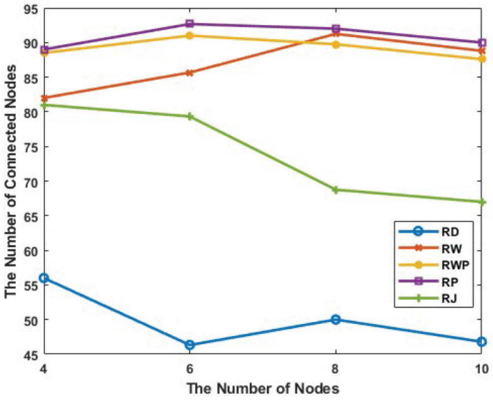
Table 7. The amounts of change in the metrics based on the number of nodes.

Area	Connected nodes	Visited nodes	Message count	Model
150x150	1.75	1	245.71	RD
	3.17	1.5	241.75	RW
	1	0.75	242.97	RWP
	0	0	248.28	RP
	0	0	243.74	RJ
200x200	7.25	3.5	256.02	RD
	4.75	0.67	276.37	RW
	3.2	1.67	223.78	RWP
	1.27	0.6	244.13	RP
	6.75	0.92	258.47	RJ
250x250	9.67	7.6	189.02	RD
	9.25	1.75	258.95	RW
	3.4	2.25	260.09	RWP
	3	1.08	262.61	RP
	14	3.42	189.04	RJ



(a) 150 pixels x 150 pixels

(b) 200 pixels x 200 pixels



(c) 250 pixels x 250 pixels

Figure 8. The number of connected nodes with respect to network size.

change between approximately 190% and 250% to the change in the number of nodes in terms of the number of messages.

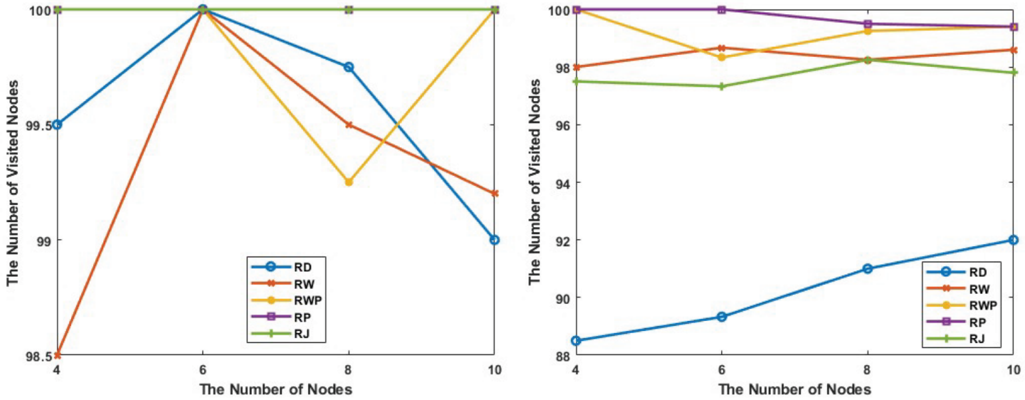
As seen in Figure 8a, the RP and RJ models succeeded in obtaining the best results in the connected node metric. Generally, the most unsuccessful model was the RW model apart from node 6.

It is seen from Figure 8b that the amount of change between the values the models produced increased as the field grew larger. The connected node metric reached the highest value in the 200 x 200 field for RP. Although RJ, another recommended method, produced values close to RW; it fell short but succeeded in producing better values than RD.

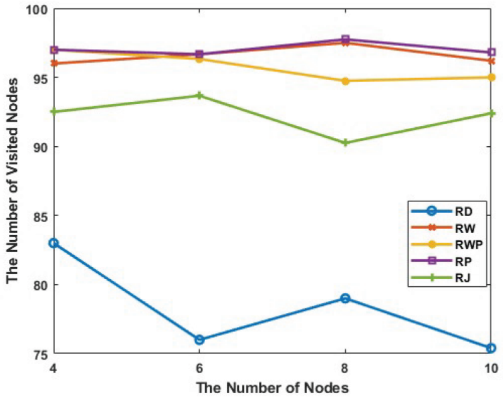
The most successful model, as seen from Figure 8c was RP. RW was close to RWP but produced better values for 8–10 nodes. The RJ model found a difference as the number of nodes increased although it approached RW for 4–6 nodes and succeeded in producing better results than RD in every situation.

As seen in Figure 9a, the most successful models for the visited node metric were RP and RJ, which we recommended. The changes in the other models were clearer, and the greatest change was observed for the RW model.

The RP model produced better results than the other methods, just as is seen in Figures 9b and 9c in a 200x200 and 250x250 field, and succeeded in providing this with less change. RWP fell short, although it



(a) 150 pixels x 150 pixels **(b)** 200 pixels x 200 pixels



(c) 250 pixels x 250 pixels

Figure 9. The number of visited nodes with respect to network size.

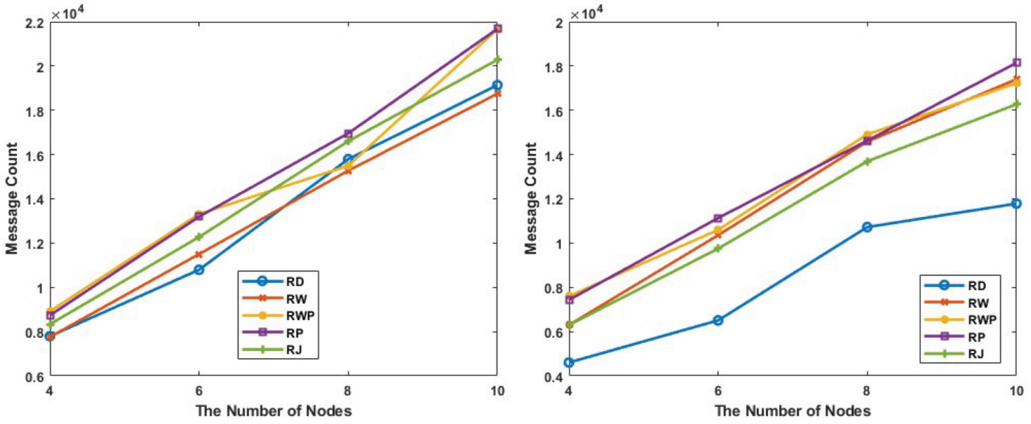
produced values close to RP in 200x200 and RW fell short, although it produced values close to RP in 250x250. RD also yielded the poorest results with the largest fluctuations.

Just as in the connected node metric, as the field grew in the visited node metric, the difference between RW and RWP increased positively in favor of RW, and the RW model succeeded in obtaining better results than the models, apart from RP. The RJ model yielded poorer results but closer to other models, although it outperformed RD.

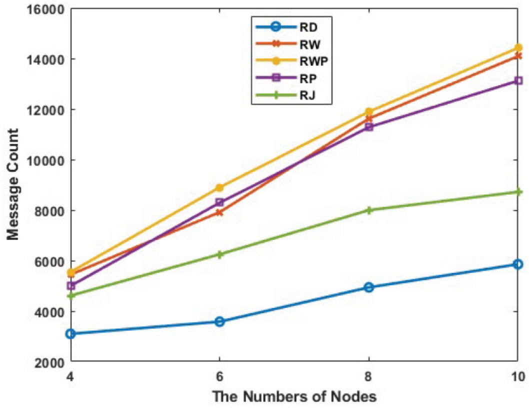
As seen in Figure 10a, all methods produced close values in terms of the number of messages metric. The recommended RP method achieved better results than the other metrics, although not by much, in terms of this metric. The poorest results varied based on the number of nodes between the RW and RD models. The RJ model succeeded on average in being one of the top three models.

As seen in Figure 10b, the RP model achieved the most successful results by broadening the difference with the other models. The RW and RWP models acquired better results than the other two methods. The recommended RJ method fell behind the models other than the RD model.

Figure 10c shows that the recommended methods fell short, although not by much, for RW and RWP in terms of the number of messages metric. Similar to previous studies, our RJ metric fell behind the RD metrics.



(a) 150 pixels x 150 pixels **(b)** 200 pixels x 200 pixels



(c) 250 pixels x 250 pixels

Figure 10. Total number of messages delivered to the BS with respect to network size.

7. Conclusions and suggestions for future work

The study proposed two new random models for applications like MCS. The performances of the two proposed models were compared in terms of three different metrics in the simulation environment created with three different existing RME models. The study expressed the results acquired for 4-6-8-10 nodes in different fields (150-200-250) in the form of three different performance metrics and analyzed the results under three different headings. It can be said that the growth of the fields was negatively affected because of the studies in terms of the performance metrics that the methods obtained. This is an expected situation. It could be possible that they exhibit a positive increase over the performance metrics in the increase in the number of nodes. The fact that the proposed RP model obtained better results than the other methods in terms of the connected node metric and visited node metrics can be evaluated as a significant success. Although prevailing methods for the number of acquired messages are few or fall behind, we consider it important that the number of visited nodes and the number of nodes transferred to the base is higher in terms of increasing the accuracy of the data collected through the provision of resource diversity within the same region. Although the other models provided greater message transfer, it can be said that data accuracy fell short because data transfer was done over the same nodes as the restricted node visit. Although RJ, another proposed method, acquired results generally close to the other methods, it fell short as the field grew larger. Obtaining better results than the other methods in relatively smaller fields and generally producing always better results than the RD model led us to believe that even better results can be produced in larger fields with various improvements in this model. In the experiments, the RP model achieved the expected success, while the RJ model could only surpass the RD model.

The first of our future plans involve making adjustments on the algorithms and the code to transform the two methods we proposed from a 2-dimensional into a 3-dimensional form. This way, with the methods we proposed, it is aimed to simulate the motions of mobile devices that move in the 3-dimensional space such as unmanned aerial vehicles and drones that have become popular recently. The performances of the currently used REMMs and the methods we proposed in the 3-dimensional space will be analyzed. Additionally, another study to be carried out on the algorithm is to calculate the delay in the access of the collected messages to the base station which is known as message delay. Likewise, by using multiple mobile nodes with the changes to be made on the algorithms, the suitability of the proposed methods for group mobility models will be tested. Optimization of the created models and improvement of them with various machine learning algorithms were added to our future plans with the assumption that these could reduce the complexity in time and space.

It is aimed to optimize the system with small interventions on the randomly selected state by maximizing our information gain by means of making choices that reduce the entropy value of the current position. As the possible new situation that will arise during the analysis of the said state cannot be projected beforehand, it is aimed to propose and try new ways based on the encountered situations.

References

[1] Zordan D, Martinez B, Vilajosana I, Rossi M. On the Performance of lossy compression schemes for energy constrained sensor networking. ACM Transactions on Sensor Networks 2014; 11 (1): 1-34. doi: 10.1145/2629660

[2] Lin Y, Shen H. VShare: A wireless social network aided vehicle sharing system using hierarchical cloud architecture. In: IEEE First International Conference on Internet-of-Things Design and Implementation; Berlin, Germany; 2016. pp. 37-48.

[3] Campbell AT, Eisenman SB, Lane ND, Miluzzo E, Peterson RA et al. The rise of people-centric sensing. IEEE Internet Computing 2008; 12 (4): 12-21. doi: 10.1109/MIC.2008.90

[4] Bilgin M, Şentürk İF. Network connectivity and data quality in crowd assisted networks. In: Ask P (editor). Crowd Assisted Networking and Computing 1st ed. Boca Raton, FL, USA: CRC Press, 2018, pp. 137-159.

[5] Goodchild MF. Citizens as sensors: the world of volunteered geography. GeoJournal 2007; 69 (4): 211-221. doi: 10.1007/s10708-007-9111-y

[6] Boulos MNK, Resch B, Crowley DN, Breslin JG, Sohn G et al. Crowdsourcing, citizen sensing and sensor web technologies for public and environmental health surveillance and crisis management: trends, OGC standards and application examples. International Journal of Health Geographics 2011; 10 (67): 1-29. doi: 10.1186/1476-072X-10-67

[7] Liu J, Shen H,Narman HS, Chung W, Lin Z. A Survey of mobile crowdsensing techniques: a critical component for the internet of things. ACM Transactions on Cyber-Physical Systems 2018; 2 (3): 18. doi: 10.1145/3185504

[8] Burke JA, Hansen M, Parker A, Ramanathan N, Reddy S et al. Participatory sensing. In: Workshop on World-Sensor-Web: Mobile Device Centric Sensor Networks and Applications; Boulder, Colorado, USA; 2006. pp. 117-134.

[9] Ra MR, Liu B, Porta TFL, Govindan R. Medusa: a programming framework for crowd-sensing applications. In: International conference on Mobile systems, applications, and services; Low Wood Bay, Lake District, UK; 2012. pp. 337-350.

[10] Carreras I, Miorandi D, Tamilin A, Ssebaggala ER, Conci N. Matador: mobile task detector for context-aware crowd-sensing campaigns. In: IEEE International Conference on Pervasive Computing and Communications Workshops; San Diego, CA, USA; 2013. pp. 212-217.

[11] Zaslavsky A, Jayaraman PP, Krishnaswamy S. ShareLikesCrowd: Mobile analytics for participatory sensing and crowd-sourcing applications. In: IEEE 29th International Conference on Data Engineering Workshops; Brisbane, QLD, Australia; 2013. pp. 128-135.

[12] Guo B, Yu Z, Zhou X, Zhang D. From participatory sensing to Mobile Crowd Sensing. In: IEEE International Conference on Pervasive Computing and Communication Workshops; Budapest, Hungary; 2014. pp. 593-598.

[13] Ma H, Zhao D, Yuan P. Opportunities in mobile crowd sensing. IEEE Communications Magazine 2014;52 (8):29-35. doi: 10.1109/MCOM.2014.6871666

[14] Zhang D, Wang L, Xiong H, Guo B. 4W1H in mobile crowd sensing. IEEE Communications Magazine 2014;52 (8):42-48. doi: 10.1109/MCOM.2014.6871668

[15] Pournajaf L, Xiong L, Sunderam V, Goryczka S. Spatial task assignment for crowd sensing with cloaked locations. In: IEEE 15th International Conference on Mobile Data Management; Brisbane, QLD, Australia; 2014. pp. 73-82.

[16] Wen Y, Shi J, Zhang Q, Tian X, Huang Z et al. Quality-driven auction-based incentive mechanism for mobile crowd sensing. IEEE Transactions on Vehicular Technology 2015; 64 (9):4203-4214. doi: 10.1109/TVT.2014.2363842

[17] Aly H, Basalamah A, Youssef M. Map++: A crowd-sensing system for automatic map semantics identification. In: IEEE International Conference on Sensing, Communication, and Networking; Singapore, Singapore; 2014. pp. 546-554.

[18] Zhang X, Yang Z, Sun W, Liu Y, Tang S et al. Incentives for mobile crowd sensing: A survey. IEEE Communications Surveys & Tutorials 2016; 18 (1): 54-67. doi: 10.1109/COMST.2015.2415528

[19] Guo B, Wang Z, Yu Z, Wang Y, Yen NY et al. Mobile crowd sensing and computing: The review of an emerging human-powered sensing paradigm. ACM Computing Surveys 2016; 48 (1): 7. doi: 10.1145/2794400

[20] Hu S, Su L, Liu H, Wang H, Abdelzaher TF. SmartRoad: Smartphone-based crowd sensing for traffic regulator detection and identification. ACM Transactions on Sensor Networks 2015; 11 (4):55. doi: 10.1145/2770876

[21] Althunibat S, Badarneh OS, Mesleh R. Random waypoint mobility model in space modulation systems. IEEE Communications Letters 2019; 23 (5): 884-887. doi: 10.1109/LCOMM.2019.2907947

[22] Nawaz H, Ali HMA. Study of mobility models for uav communication networks. 3c Tecnología 2019; 8 (29): 276-297. doi: 10.17993/3ctecno.2019

[23] Guillen-Perez A, Cano MD. Flying ad hoc networks: A new domain for network communications. Sensors 2018; 18 (10): 3571. doi: 10.3390/s18103571

[24] Petit J, Lambiotte R, Carletti T. Classes of random walks on temporal networks. Applied Network Science 2019; 4 (1): 72. doi: 10.1007/s41109-019-0204-6

[25] Wu Q, Liu H, Zhang C, Fan Q, Li Z et al. Trajectory protection schemes based on a gravity mobility model in IoT. Electronics 2019; 8 (2): 148. doi: 10.3390/electronics8020148

[26] Hussaini M, Naeem MA, Kim BS, Maijama'a IS. Efficient producer mobility management model in information-centric networking. IEEE Access 2019; 7: 42032-42051. doi: 10.1109/ACCESS.2019.2907653

[27] Hussaini M, Nor SA, Ahmad A. PMSS: Producer mobility support scheme optimization with RWP mobility model in named data networking. International Journal of Communication Networks and Information Security 2018; 10 (2): 329-339. doi: 10.11591/ijece.v8i6.pp5432-5442

[28] Yoshimura Y, Sinatra R, Krebs A, Ratti C. Analysis of visitors' mobility patterns through random walk in the Louvre museum. Journal of Ambient Intelligence and Humanized Computing 2019;1-16. doi: 10.1007/s12652-019-01428-6

[29] Samouylov KEE, Gaidamaka YV, Shorgin SY. Modeling the movement of devices in a wireless network by random walk models. Informatics and its Applications 2018; 12 (4): 2-8. doi: 10.14357/19922264180401

[30] Johnson DB, Maltz DA. Dynamic source routing in ad hoc wireless networks. In: Imielinski T, Korth HF (editors). Mobile Computing. Boston, MA, USA: Springer, 1996, pp. 153-181.

[31] Camp T, Boleng J, Davies V. A survey of mobility models for ad hoc network research. Wireless Communications and Mobile Computing 2002;2 (5):483-502. doi: 10.1002/wcm.72

[32] Broch J, Maltz DA, Johnson DB, Hu YC, Jetcheva J. A performance comparison of multi-hop wireless ad hoc network routing protocols. In: IEEE International Conference on Mobile Computing and Networking; Dallas, Texas, USA; 1998. pp. 85-97.

[33] Chiang CC, Gerla M. On-demand multicast in mobile wireless networks. In: International Conference on Network Protocols; Austin, TX, USA; 1998. pp. 262-270.

[34] Young-Bae K, Nitin V. Location-Aided Routing (LAR) in mobile ad hoc networks. Wireless Networks 2000; 6 (4): 307-321. doi: 10.1023/A:1019106118419

[35] López MS, ManzoniSánchez P. ANEJOS: A Java based simulator for ad hoc networks. Future Generation Computer Systems 2001; 17 (5): 573-583. doi: 10.1016/S0167-739X(00)00040-6

[36] Davies VA. Evaluating mobility models within an ad hoc network. MSc, Colorado School of Mines, Colorado, USA, 2000.

[37] Garcia-Luna-Aceves JJ, Madruga EL. A multicast routing protocol for ad-hoc networks. In: IEEE Computer and Communications Societies; New York, USA; 1999. pp. 784-792.

[38] Bar-Noy A, Kessler I, Sidi M. Mobile users: to update or not to update?. Wireless Networks 1995; 1 (2):175-185. doi: 10.1007/BF01202540

[39] Rubin I, Choi CW. Impact of the location area structure on the performance of signaling channels in wireless cellular networks. IEEE Communications Magazine 1997;35 (2):108-115. doi: 10.1109/35.565672

[40] Zonoozi MM, Dassanayake P. User mobility modeling and characterization of mobility patterns. IEEE Journal on Selected Areas in Communications 1997;15 (7):1239-1252. doi: 10.1109/49.622908

[41] Basagni S, Chlamtac I, Syrotiuk VR, Woodward BA. A distance routing effect algorithm for mobility (DREAM). In: ACM/IEEE international conference on Mobile computing and networking; Dallas, Texas, USA; 1998. pp. 76-84.

[42] Royer EM, Melliar-Smith M, Moser LE. An analysis of the optimum node density for ad hoc mobile networks. In: IEEE International Conference on Communications; Helsinki, Finland; 2001. pp. 857-861.