Survey on Mobility Model of Opportunistic Networks

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Abstract—T Opportunistic networks is a kind of self-organizing networks which does not need the complete communication paths between the source node and the destination node. They transfer messages through communication opportunities arising from nodes movement. Because the message transmission opportunity depends on the movement of nodes, the mobility model becomes an important research hotspot in the opportunistic networks. Meanwhile mobility models are usually used for simulation purposes when new network protocols are evaluated. Firstly, this paper outlines the significance and classification of mobility model, and shows the classical mobility models at the present stage. Secondly, we summarize the mobility characteristic of nodes, and compare and analyze the classical mobility models. Finally, we summarize the existing problems and challenges for the current mobility model and look forward to the future research and development.

Keywords-Opportunistic networks; Mobility model; Survey

I. INTRODUCTION

With the rapid development of computer science and communication technology, a large number of intelligent devices with wireless communication capabilities continue to emerge. The potential trend of development promotes the rapid development of wireless ad hoc networks applications such as, cell phone, PDA and other handheld electronic devices. These devices with the help of Bluetooth or Wi-Fi interface can set up a self-organizing network to share data [1]. Intelligent equipment for vehicles is used to form a mobile vehicle network to monitor the state of the vehicle [2]. Sensors used in the wild animals to collect the activity data of the animals [3] are composed of the mobile sensor network and so on.

The practical applications which are mentioned above require new communication models. Traditional communication mode can-not meet the needs of these applications because the MANT (Mobile Ad hoc networks) requires ADOV (Ad hoc on-demand distance vector routing) [4], DSR (Dynamic Source Routing) [5] and other routing protocols to establish end-to-end communication path before data transmission. The WSN (Wireless Sensor Networks) needs to establish convergence tree through the CTP (Collection Tree Protocol) [6]. The above two communication mode networks are connected for most of the time. There is at least one complete end-to-end communication path between the nodes, and the nodes can achieve data transmission.

In the opportunistic networks, the network can be divided into many disconnected sub-regions because of the sparse nodes, the obstacles and other reasons. The sub-regions are disconnected most of the time. The source node and destination node may be located in different regions. So the MANT and WSN can-not establish routings to the target node. However, incomplete communication paths between source node and destination node do not mean that communication can-not be achieved. When some nodes move, they lead to nodes meeting opportunity. Data exchange can be realized when a node is in the communication range of the other node [7]. The opportunistic networks make use of this opportunity to achieve data communication from the source node to the destination node.

Opportunistic networks that do not require full connectivity of the network and traditional sensor network data collection methods constitute an important complementary [8-13]. Opportunistic networks have aroused wide attention in the academic circles [14-15]. A series of important achievements have been made by the international academic circles at major conferences [16-27]. Key universities and professional academic institutes around the world have also started the related work.

Nodes can forward messages only when they meet each other in the opportunistic networks. The encounter probability and the time distribution of the nodes are determined by the node mobility model, so compared to

traditional MANT, node mobility model is more important to opportunistic networks [28]. Mobility model has become an important research hotspot in opportunistic networks. However, opportunistic network nodes have the characteristics of self-organizing and variability, which make it very difficult to study and analyze them. So it is hoped that node mobility model should be established in order to find inherent characteristics and rules. In recent years, many researchers have put forward a lot of node mobility model. Such as: Random Way Point mobility model (RWP) [29-30], Random Walk mobility model (RW) [31], Random Direction mobility model (RD) [32], etc. These models use the knowledge of kinematics to construct the mobility model in theory. There are also some researchers who have used statistics methods and real scenarios to establish node mobility model. Such as, the Reality Mining project of MIT [33], the Wireless Topology Discovery project of UCSD [34-35],the Haggle project of Cambridge [36]，and the DieselNet project of UMass [37]. These research works have made a lot of achievements.

We try to summarize the research work of predecessors, and put forward our viewpoints. The remainder of this paper is organized as follows. Section 2 describes the significance and classification of node mobility model. We list the typical mobility models in section 3. Section 4 compares and analyzes the typical mobility models. And section 5 concludes overall paper and looks future research directions.

II. MOBILITY MODEL CLASSIFICATION

Mobility model defines the algorithm and rules of node mobility in opportunistic networks, and describes the way of node movement. There is no intact path between node pair in opportunistic networks. The communication among nodes mainly depends on the encounter opportunities offered by the mobile nodes. The mobile ways of nodes decide message transfer results between nodes, so the mobility model impacts directly the network performance, such as network throughput, routing overhead and transmission success ratio. It is observed that mobility model can describe the moving rules of the mobile nodes which is an important study basis for opportunistic networks.

Mobility model provides the node moving scenario for simulation researches of opportunistic networks. It can describe the location, speed and direction change of mobile nodes in the networks. Previous studies have shown that the effects of different mobility models on the performance of network protocols or algorithms are also different [38-39]. The diversification and the inherent characteristics of mobility model will bring direct impact on the simulation and evaluation of the network performance [40]. Therefore, the research on the mobility model is an important research direction in opportunity networks.

With the development of the modeling and research of mobile nodes, a large number of mobility models have emerged. Different researchers used different methods to classify the mobility model. The literature [41-42] introduces the mobility model classification from four aspects: the mobile characteristics of nodes, the constructive mode of mobility model, the relationship between nodes, and the node speed relation. Specific classification methods are summarized as follows.

TABLE 1. THE CLASSIFICATION BASED ON THE NODE MOBILE CHARACTERISTICS

Classification	Features	Representative
Random mobility model	Random selection speed and direction of node movement	Random walk model(RW)
		Random direction model(RD)
		Random waypoint model(RWP)
Restricted mobility model	Node movement is influenced by current or historical factors.	Road mobility model
		Obstacle movement model

TABLE 2. THE CLASSIFICATION BASED ON THE CONSTRUCTIVE MODE OF MOBILITY MODEL

Classification	Features	Representative
Tracking movement model	Tracking the mobile model of the real world, access to node traces	Reference point mobility model
		Queue mobility model
		Group mobility model
		Pursuit movement model
Synthetic mobility model	Based on theory and subjective experience	Random walk model(RW)
		Random direction model(RD)
		Random waypoint model(RWP)

TABLE 3. THE CLASSIFICATION BASED ON THE RELATIONSHIP BETWEEN NODES

Classification	Features	Representative
Individual movement model	The nodes are independent of each other	Random walk model(RW)
		Random direction model(RD)
		Random waypoint model(RWP)
		Gauss- Markov model(GM)
Group mobility model	There is a certain relationship between the nodes.	Reference point mobility model
		Queue mobility model
		Group mobility model
		Pursuit movement model

TABLE 4. THE CLASSIFICATION BASED ON THE NODE SPEED RELATION

Classification	Features	Representative
Stochastic velocity model	Mobile random selection speed	Random walk model(RW)
		Random direction model(RD)
		Random waypoint model(RWP)
Temporal dependencies	The current speed of the node is related to the previous speed	Gauss- Markov model(GM)
		Smooth random model(SR)
		Semi Markov model(SM)
Spatial dependencies	The speed of different nodes is spatially correlated.	Reference point mobility model
		Queue mobility model
		Group mobility model
		Pursuit movement model

TABLE 5. THE CLASSIFICATION BASED ON THE INITIAL MODELING DIRECTION

Classification	Features	Representative
Mobility model based on the theory	Modeling from the theory	Random walk model(RW)
		Random direction model(RD)
		Random waypoint model(RWP)
		Gauss-Markov model(GM)
		Smooth random mobility model(SM)
Mobility model based on the real networks	Modeling from the real opportunistic networks	Event driven mobility model
		Working day mobility model
		Community based mobility model
		Reference point group mobility model
		Map based mobility model

With reference to the above classification idea, we put forward the classification method based on the initial modeling direction in this paper. We divide the mobility model into two types. The first one is the mobility model based on the theory, and the other type is the mobility model based on the real networks. The former sets the node movement parameters by artificial hypothesis, and tries to reveal the node movement rules. Then we can design opportunity routing algorithm to forward messages between the nodes based on the node movement rules. The latter, based on the actual network in the real world, observes and statistics the running parameters of opportunistic networks, tries to find out the general rules of mobile nodes, and then establishes a network mobility model. The proposed classification is shown as table 5.

III. TYPICAL MOBILITY MODEL

At present, according to different kinds of opportunistic networks, domestic and foreign scholars have put forward a variety of node mobility model and have carried out a detailed exposition. We will not describe concretely the content of the model in this paper but only list and introduce in brief the classical mobility model.

A.   *The Mobility Model Based on the Theory*

Random walk model. It is one of the earliest mobility models [43-44]. The model is based on the famous Brown motion model in physics. The model is a simple model that is randomly selected in a certain range with the degree and direction of the model. In one dimensional or two-dimensional space, the model will return to the initial position of the node. This feature ensures that the nodes move only around the initial position and not move out of

the simulation area. But the current speed and direction of the node in the model is not related to the previous moment. It is a completely independent movement mode. So, this model would suddenly stop or turn the movement. When the fixed time or fixed distance is too small, the nodes will only move in a very small area in the initial position, which leads to the uneven distribution of the node space. Therefore, in the network simulation, area chosen should be relatively large or it is important to guarantee the mobility of the nodes in the whole network.

Random direction model. Random direction mobility model [45] is a kind of mobility model proposed by Royer et al. It overcomes the problem that the probability of node passing through the simulation area is relatively high. The model has the characteristics of simple, flexible and easy to implement. So, it has been applied to many simulation experiments. However, there are some shortcomings in this model. Such as in the two-dimensional space, the mobile node is mainly distributed on the edge; the model only focuses on the direction of motion of the nodes, and can not be a good reaction node moving state. On the basis of this model, some scholars have improved the model. Such as: Modified Random Direction Model, Constant Velocity Random Direction Mobility Model.

Random Waypoint model. Random waypoint mobility model [46] is one of the most widely used node mobility models. It includes pause times between changes in direction and speed. A mobile node stays in one location for certain period of pause time. In original model, mobile nodes are distributed randomly in the simulation area between speed [V_{min}, V_{max}]. After reaching the destination, the node stops for a duration defined by the ''pause time'' parameter. After this duration, it again chooses a random destination and repeats the whole process again until the simulation ends.

This process is repeated after choosing pause time from interval [P_{min}, P_{max}]. The model is easy to implement. It has been favored by researchers and has a wide range of applications. However, studies have found that the model has the following deficiencies. Firstly, the average rate of the node in the simulation process is attenuated with the increase of time, which leads to error in the simulation results. Secondly, the spatial distribution of nodes in the simulation process will be changed. The initial state is the uniform distribution of nodes, which can change the distribution of non-uniform distribution. At the same time, the node can generate boundary effect. The longer the pause time, the smaller is the boundary effect. Finally, the model is a memory-less mobility pattern because it retains no knowledge concerning its past locations and speed values. Its movement is not smooth. So it does not conform to the reality of the node's movement law. By improving the model, some scholars have put forward Random Border point Model and Restricted Random Waypoint.

Gauss-Markov model. This model was designed initially for the simulation of a PCS, to attain different level of randomness with tuning parameter α (0< α <1). At fixed intervals, the simulator generates a new speed and direction based on their current values and standard deviations. It uses the following equations to calculate new values for speed and direction at fixed intervals [47].

$$s_n = \alpha s_{n-1} + (1-\alpha)\bar{s} + \sqrt{(1-\alpha^2)}s_{x_{n-1}} \qquad (1)$$

$$d_n = \alpha d_{n-1} + (1-\alpha)\bar{d} + \sqrt{(1-\alpha^2)}d_{x_{n-1}} \qquad (2)$$

Where, s_n is the new speed and s_{n-1} is the current speed. d_n is the new direction and d_{n-1} is the current direction. α is a variable that controls the degree of randomness. $s_{x_{n-1}}$ and $d_{x_{n-1}}$ are random numbers taken from standard Gaussian distribution. $\bar{s}$ and $\bar{d}$ are the average of speed and direction.

The GM model reflects the way of moving nodes. It provides a better way to deal with nodes moving to the edge of the simulation area. In this model, the speed of the nodes is correlated. Therefore, it overcomes the problem of velocity attenuation and avoids the rate or direction of abrupt behavior. It is important that the spatial node distribution is uniform. However, the speed of the node in the model is the Gauss random variable of the previous interval velocity at any time interval. If parameter α is not equal to 1, the node does not move in a straight line, and the whole simulation process is not suspended. Examples of some other similar models are semi-Markov smooth mobility model and a smooth Gauss-semi-Markov mobility model.

B. Mobility Model Based on Real World

With the deepening of research, researchers have found that although the node mobility model based on theory is simple and easy to implement, they do not reflect the node's true moving trajectory. Researchers thus began to explore the mobile trajectory of the real world. So far, great achievements have been made on the mobility model based on the real world.

Event driven mobility model. Event driven mobility model [48] was first proposed by Chang. In real life, there are work, school, meetings and other events, which cause human beings to move to different places at different times. Based on this viewpoint, firstly, the event driven mobility model uses the improved colored Petri net (meta CP-net) to describe the 3 basic "move - stop" movement patterns of mobile nodes. Then it generates a colored Petri net (CP-net) of the mobile node based on the event of the node. Finally, the motion trajectory of large-scale nodes is generated by CP-net based on a series of motion rules. Inspired by this kind of movement model, the researchers put forward many event driven mobility models. A state

transition and event triggered opportunistic network node mobility model is proposed in the paper[49].The model abstracts the node's mobility patterns into three states, such as the main community, the other communities, and the path to which they are linked. According to the social relationship and the driving function of the social activities of the nodes in the real life, the paper proposes a node mobility model based on the similarity of the user's interest [50].In this model, the degree of interest of nodes is abstracted as an interest probability matrix, and the Pearson correlation coefficient is used to calculate the similarity of the nodes.

Working day movement model. Researchers have put forward a working day movement model based on the observation and statistics of human daily life. In the working movement day model [51], nodes imitate the social activities of human beings in their daily life and work. Such as: going to work in the office or going to school; going to the supermarket to shop; getting together with friends; sleep or rest, etc. The model includes a different way of moving, that node can be a separate mobile or group of groups to walk, drive or take the bus. This way of individual movement or group movement at different speed increases the heterogeneity of the movement, and it also affects the performance of the routing. In addition, the working day movement model also introduces the relationship between community and society.

Community based mobility model. Researchers have put forward a community based mobility model to show the characteristics of the community according to the node's movement track. The node of the model is based on the three situations to make decisions in the next step of moving location.1) Node interest. Nodes are more likely to go to a particular location or encounter a particular node, depending on their interests. 2) Node heterogeneity. Some nodes can reach all locations or meet all other nodes. 3) Behavioral degeneration. Nodes move according to time variation. Musolesi put forward a kind of community based mobility model combined with social network theory[52].The model will be distributed in multiple communities in different regions according to the degree of closeness between nodes. Then the model calculates the attractiveness of different communities to each node, and determines whether the node is moving and moving toward which target area. Spyropoulos [53-54] proposed time variant community mobility model. The work cycle of each node is composed of the normal mobile period and a centralized mobile cycle. For each cycle, the node randomly selects a community as its local community. There are two mobile states at each node of the cycle, Local epoch and Roaming epoch. The former is selected to move within the local community, the latter is roaming elsewhere. The node switches between two states with a certain probability to form a Markov chain. Probability size is determined by the period of the movement.

Reference point group model. Reference point group mobility model [55] is the most widely used group mobility model. The model is described as follows: Nodes are divided into different groups at the beginning. Each group has a logical center. The motion of a group member is determined by a logical center, and each node has a reference node that points to the group motion. The motion of the reference node is based on the movement of the group. The motion of a single node is determined by the group motion vector and the reference point motion vector of a single node. The group's movement consists of a set of pre-specified test points.

Each group has a logical center, which can be set up in advance or selected completely randomly. The mobile nodes are distributed in the logical center. The movement property of the logical center defines the movement of the group node, including the position, speed, direction and acceleration.

A reference point is assigned to each node in the group, and the reference point moves along with the group. Nodes are freely distributed around the reference point and move independently around the reference point. The reference point provides the configuration parameters for the node.

According to different applications and characteristics, domestic and foreign scholars have put forward a variety of improved model based on RPGM model. These models are partly derived from the RPGM model or some of the basic features of the RPGM model. They mainly include: reference speed group mobility model, based on the virtual trajectory of the mobility model, the queue mobility model, nomadic group mobility models, the pursuit of mobility model, long and narrow group mobility model.

Map based mobility model. In order to better simulate a real scenario, researchers put forward a lot of map based mobility model. A new mobility model based on maps is proposed in the paper [56].The model is the movement of the nodes in the path of a predefined real map. In the ONE simulation tool [57], three kinds of mobility models based on maps are included. They are random Map-Based Movement (MBM), shortest Path Map-Based Movement (SPMBM) and routed Map-Based Movement (RMBM). MBM is the basic model proposed by the first. In this model, the nodes are randomly selected in a real map. Because the model can not reflect the reality of human activities, the researchers put forward more true reflection of the human activities of the SPMBM mobility model. In this model, nodes are randomly selected for a target location in the map. The model uses the Dijkstra shortest path algorithm to find the shortest path from the current position to the target position. This target location can be selected randomly or selected from the list of points of interest. These points of interest are like real life places, such as tourist attractions, shops, schools, restaurants, etc. Based on the RMBM model, the SPMBM model is proposed. The nodes in this model can be carried out according to the preset route, such as bus line, subway line and pedestrian road.

IV. COMPARISON AND ANALYSIS FOR THE TYPICAL MOBILITY MODELS

A. The Characteristics of Node Movement

The Mobile features of nodes are one of the important foundation and basis of node mobility modeling. The goal of node mobility modeling is to better reflect the characteristics of the mobile nodes and to guide the practical application. This section summarizes a large number of research results, we summed up the characteristics of node mobility, including: randomness, collaboration, self-organization, temporal correlation, spatial correlation, geographical constraint.

Randomness. It refers to the node's movement speed, direction, destination and so on with the movement of randomness. By analyzing the practical application of the nodes, we can find that these objects or people have some randomness. Therefore, the nodes in the node mobility model should have some randomness.

Collaboration. Different nodes must have cooperation. For nature, the development and survival of all things can not do without the cooperation and help of other species in society. The message transmission of the opportunity network is one of the nodes cooperate with each other to transmit the message from the source node to the destination node. Therefore, the model should reflect the cooperation of nodes.

Self-organization. It refers to a group of nodes spontaneously organized according to their own needs, interests, or purpose. Such as, people organize teams according to their interests and hobbies. Animals go hand in hand according to their own needs. Therefore, the node should have a certain self - organization.

Temporal correlation. It has two meanings. On the one hand, it refers to the speed and direction of node movement with a time correlation, That is, the current speed and direction of the node is related to the speed and direction of the previous time node. On the other hand, it refers to the time period effect of node's movement. Different time period nodes have different states. Mobility and immobile state of node have time correlation.

Spatial correlation. It is used to determine how the node is dependent on the movement. If the nodes are moving in the same direction, they have high spatial correlation.

Geographical constraint. It shows that the node's movement will be affected by geographical factors such as: buildings, roads, rivers, and other obstacles.

B. Comparison and analysis

From the brief introduction and analysis of the model of node mobility in different research ways we find that, at present, the research on the node mobility model is getting more and more intensive, and the application scope becoming wider. In order to facilitate the comparative analysis of these research results, this paper will make a comparative analysis of the above models. We describe their advantages and disadvantages based on the theory of node mobility model and the mobile model based on the real world in Table 6. We analyze and compare the performance of the node mobility model based on theory from the following 7 aspects. In table 7, including: Parameters, motion stage, smoothness, velocity attenuation, uniform distribution of nodes, model description, controllability.

TABLE 6. COMPARISON OF THE DIFFERENT MOBILITY MODELS

Model	Advantages	Disadvantages
Based on the theory of moving model	Simple,	Single parameter,
	Flexible,	Too random,
	Easy to implement,	Too theoretical,
	Having rigorous theoretical basis.	Not suitable for practical application.
Based on real world of mobile model	Social attributes,	Complex model,
	Real movement characteristics.	Single application range,
		Doing not have universal and regularity.

TABLE 7. THE PERFORMANCE COMPARISON OF THE CLASSICAL MOBILITY MODELS

Model	RW	RD	RWP	GM
Parameters	v, θ	v, θ, T	V,D	v, θ
Motion stages	{move, pause}	{move, pause}	{move, pause}	{move}
Smoothness	no	no	no	yes
Velocity attenuation	Possible	no	yes	no
Uniform distribution	nearly	yes	no	yes
Description of angle	macroscopic	macroscopic	macroscopic	microcosmic
Controllability	low	low	low	high

V. Summary and Outlook

In summary we find that the research on node mobility model has achieved fruitful results. However, at present, the modeling of mobile network nodes is still in its infancy. At this stage, all node mobility models, whether it is based on the theory of mobile model or based on the real world mobile model, have some shortcomings. These issues require in-depth study of the contents in the future and summarized as follows:

(a) Mobility model cannot reflect the real environment of the mobile node. Researchers establish node mobility model, which is a way to simulate the movement of the node in the real environment. However, most of the existing mobility models are not completely consistent with the way of moving nodes in the real environment, and can not simulate the real movement of nodes. On the one hand, the researchers use the existing theorem, the law of the design of the mobility model, and mathematical knowledge to describe the model. The model established in this way has the characteristics of mechanization, single function and monotonous design, and there is a certain gap between the simulation environment and the real environment. On the other hand, the researchers analyze and sum up some rules and establish the node mobility model based on the social characteristics of human beings. This model can only reflect a part of the nodes of the mobile characteristics and is not comprehensive.

(b) The different parameters in the mobility model have a great influence on the simulation results. Different parameters will not only form different network topology, but will also be the center of the node clustering, edge clustering and node speed and direction of the phenomenon of mutation. In the real environment, the node's movement is affected by multiple factors, and the limited parameters can not respond well to its characteristics. Simulation data are based on the results of parameter selection, and the results obtained can not accurately reflect the performance of the network.

(c) There is no unified framework for mobility model. Most of the existing mobility models are a single model, which can only react to the specific characteristics of the node. Each model is independent of each other. There is no unified framework to constrain or connect them, so that the model has limitations and can not reflect the true nature of the node

Based on the shortcomings of the above node mobility model, we look forward to   research content from the following aspects.

- Most of the current mobile model only reflects the characteristics of the node moving direction, moving speed. To determine the actual node mo-

bility needs us more research. Although some researchers and institutions have done some actual node mobility experiments, and achieved some experimental data and results. However, most of these properties are still in theoretical derivation and simulation. The relationship between the characteristics of these models and how to describe these characteristics are the focus of future research.

- Many models have been proposed based on the social characteristics, but the application of these models is not a lot. Most of the simulation is based on the theory of mobility model. On the one hand, based on the theory of moving model, it is easy to implement, and control the position, direction and speed of the node. On the other hand, the model of social characteristics is relatively complex, and the characteristics of node are single. We should propose a better and more practical node mobility model in the future. Mobility model is not only to reflect the characteristics of node mobility, but also to meet the needs of the application environment of nodes. We believe that with more in-depth research on the opportunity network model, it is bound to put forward a new model that meets the requirements.

- For the node mobility model, if the model has many parameters, the model will be more close to the real node mobility characteristics. But the model is more complicated. However, the ideal node mobility model is as simple as possible and the parameters are as little as possible. In the reality, modeling is often done by compromising the accuracy and complexity of the model. In the future, the development of mobility modeling is bound to be cross domain and cross disciplinary integration. We can combine the opportunity to network node mobility model and social network and other networks to study.

- Unifying these mobility models will also be a hot topic in the research of future node mobility models. At present, there is no unified framework to establish node mobility model. We should have the courage to innovate, break the thinking mode of the existing mobility model and put forward a unified model framework for the mobility model. This is a very good development direction.

- At present, we build a model in one dimensional or two dimensional spaces. With the development of technology and the development of intelligent devices, such as unmanned aerial vehicles, the mobile model also needs to be extended to three-dimensional or multi-dimensional spaces. The mobility model of the three dimensional space will have more application value.

This paper briefly introduces the significance of mobility model and classical classification methods. We list the typical mobility models and summarize the node move-

ment characteristics that have been discovered. Then we compare the advantages and disadvantages for classical mobility models, and point out the research directions in the future.

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