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Quality of Service in WiMAX: Real World Aspects of Social & Environmental influences on Mobility

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Abstract

In today's technological world, users of mobile wireless devices are predominantly on the move while still enjoying connectivity of the Internet. How people use their mobile devices differ in many ways, not only from a technological point of view e.g. browsing the web, sending emails, SMS, downloading music/apps, or keeping up with friends on facebook, etc. But also from a geographical point of view, the user's physical location, whether this is seated stationary in a park or shopping centre, where the user may only change location if the connection is poor, or actively mobile while interacting via the Internet, e.g. walking to work/college, while using VoIP/Skype or streaming media clips. Theoretically modelled nodes have an uninterrupted straight path to their next destination in simulations, whereas in the real world this is extremely unlikely to be true with the average human meandering down the street, while concentrating on their mobile device. It is important to determine through simulating the proposed QoS protocols with WiMAX connectivity, whether the perceived improvement will actually function under the planned usage, consequently it is therefore vital to replicate the reality of user behaviour. This work investigates a variety of mobility models including Transportation Theory, Random Walk, and Gauss Markov models, and how it affects connectivity within WiMAX. Each model has been simulated using NS3 and compared to ascertain the most effective method to replicate typical user movement to ensure that today's Mobile Ad hoc Networks (MANET) have been designed with the mobile user in mind.

Keywords: Quality of Service, QoS, WiMAX, streamed media, Mobility Models, Transportation Theory, Random Walk, Browian model, Guass Markov

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Introduction

In today's technological world, users of mobile wireless devices are predominantly on the move while still enjoying connectivity of the Internet. How people use their mobile devices differ in many ways, not only from a technological point of view e.g. browsing the web, sending emails, SMS, downloading music/apps, or keeping up with friends on social network sites, etc. But also from a geographical point of view, the user's actual physical location, whether this is seated stationary in a park or shopping centre, where the user may only change location if the connection is poor, or actively mobile while interacting via the Internet, e.g. walking to work/college, while using VoIP/Skype or streaming media clips, (Briesemeister, Hartenstein, & Pérez-costa, 2004).

It is important to determine when simulating any QoS protocol, whether the perceived improvement will actually function under the planned usage, consequently it is vital to replicate the reality of the users behaviour (Camp, Boleng, & Davies, 2002; Davis, Eisenhardt, & Bingham, 2007). This is why researchers have investigated the characterisation of user behaviour in various network situations (Resta & Santi, 2006), such as the Dartmouth Campus (Jain, Lelescu, & Balakrishnan, 2005; Kim & Kotz, 2005), here data collected from the IEEE 802.11 access points around the campus was analysed to determine actual user mobility. It has been identified that such specialised scenarios can limit the usefulness of the user model, and as a result the more general models can be an advantage (Resta & Santi, 2006). Consequently the environment in which the user inhabits can influence the way in which they will use their mobile devices, as in the Dartmouth Campus scenario. Therefore it is imperative to model generic user behaviour when simulating wireless protocols to represent the assumed reality of the actual mobility of the node's that will potentially utilize these protocols (Lee & Hou, 2006).

There are two core categories of mobility models, traces and synthetic models (Sanchez & Manzoni, Jan 1999). Traces once developed provide accurate information of the user's mobility, as they collate the actual mobility of the user that is observed over a period of time. The longer the period of observation coupled with a large number of participants produce precise data for example as in the Dartmouth Campus results (Lee & Hou, 2006). The disadvantage of this is that it is very intricate to model within a network environment (Law, 2007). Also the trace has to be created before it can be tested, if the protocol has not yet been implemented, it is therefore impossible to first create the trace for testing a new protocol (Camp, Boleng, & Davies, 2002). Also traces can be constrained to the movement within the scenario they have been recorded, for instance mobility on campus may differ to that recorded in a shopping centre. On the other hand the synthetic mobility model simulates the expected mobility of users, rather than emulates the actual movement of users as does the traces. The synthetic models still encompass changes in speed direction and in some the actual distance in ad hoc user behaviour. Kim, M; Kotz, D; Kim, S; (2006) validated their trace model by comparing synthetic traces with real traces, they concluded that synthetic traces match real traces with a median relative error of 17%, (Kim, Kotz, & Kim, 2006). Therefore inferring synthetic mobility models are adequate to model new protocols.

Therefore within the simulated environment it is essential to reflect the movement of the perceived user. In recognition of this several mobility models have been developed which encompass the Brownian Motion (Brown, 1828) and Random Walk (RW) (Johnson & Maltz, 1996), mobility models which also comprise models within transportation theory that have been incorporated in simulations of mobile networks (Briesemeister, Hartenstein, & Pérez-costa, 2004; Briesemeiter & Hommel, 2000; Helbing, 2001).

1. TRANSPORTATION THEORY

Transportation theory depends on defining a geographical area of service, then calculating the loading of that service, while simultaneously calculating how the systems can balance the load distribution. The variables under consideration to determine the load are the purpose of the movement together with the route that will be taken to the destination along with the assumed population of the defined area incorporating both residential and business environments. Within such a defined area, timing of peak activity needs to be determined along with where within the geographical area the peak load occurs. Therefore the key parameters would be the total capacity and of the area, as this would dictate the maximum potential load. Mobility models within this paradigm are City Area, Area Zone and Street Unit Zone models

- City Area models assume a densely populated core to the area that includes road transport network that allows movement from the edge of the area to the centre (Jain & Tewari, 2012). This is not always the case as in some city areas the population density can be dispersed but the industrial centres are often now on the edge of the cities. For instance docks and out of town shopping centres, meaning the actual traffic flow can be opposite to that expected in the city area models.
- Area Zone divides the city into regions based on an orthogonal grid, useful for modelling large scale interactions (Camp, Boleng, & Davies, 2002). This model can be fine tuned to emulate a variety of modern city scenarios.
- Street Unit Model focuses on the movement of individual nodes, predominately the individual travelling time incorporating speed restriction en-route with the aim to model realistic traffic conditions (Camp, Boleng, & Davies, 2002).

Current transportation models lack the ability to calculate the physical movements of the actual nodes, as these are theoretical based models which aim to define realistic simulation environments encompassing typical obstacles and travel routes. The limitations of the accuracy of the realism means that a high amount of computational power is required to cope with the complexity of simulating such high levels of realism. Currently the amount of computational power available can constrain the validity of the actual results of the simulation.

2. BROWNIAN MOTION MODEL

The Brownian Motion Model had been initially defined by Robert Brown (1827) who noticed the random wiggling behaviour of pollen grain in water as he observed them through a microscope, (Brown, 1828), see figure 1. Though it is thought Jan Ingen-Housz was the first to record irregular movement from observing coal dust on the surface of alcohol in 1785, (Ingen-Housz, 1784), it was Brown that was credited with the discovery, due to his thorough analysis of the concept. Brown tried to determine what was causing the randomness of the pollen grain movement (Brown, 1828; Helbing, 2001). From his experiments Brown determined that "*the Brownian motion model that is everywhere infinite is an idealised approximation to actual random physical processes, which always have a finite time scale*" (Mörters & Peres, 2008). From this he initially produced a simple mathematical model $x_t$where x is the motion and *t* represents time which has many real-world applications that is even relevant today (Ludkovski, 2007).

Abbott et al's (1996) inferred the importance of the Brownian model over time, in that Thervald Thide (1880) was the first mathematician to research Brownian's model, as he incorporated it into his work on the method of least squares in 1880 (Abbott, Davies, Phillips, & Eshrahian, 1996). Louis Bachelier (1900) also used the model in his PhD thesis that analysed the stock markets, in which the Brownian model still has influence today. Mathematically, the Brownian motion is described by the 'Wiener' process (Henry & Woods, 2002; Revuz & Marc, 2008) which can be constructed as the scaling limit of a RW with stationary independent increments, this is recurrent in one or two dimensional scenarios. Therefore it returns to any fixed area of the origin infinitely often, though this is not the case in the 3D sphere.

Following on from the work Brown (1828) had accomplished, Einstein analysed Brownian motion and is rumoured to have encompassed it into his research on the existence of atoms, which he later discounted as unimportant (Einstein, 1956; Sánchez & Manzoni, 2001; Abbott, Davies, Phillips, & Eshrahian, 1996). From this work, Einstein was the first to mathematically explain Brownian motion. Amazingly, commencing from the simple works of a botanist nearly two centuries ago Brownian motion still has significant importance in twenty first century modern science from physics through to today's computer science technology.

3. RANDOM WALK

Natural movement is random and unpredictable. Consequentially the RW Mobility Model was developed to imitate this phenomenon, often referred as the drunkards walk (Resta & Santi, 2006). The model is designed to formalise the trajectory of the node moving from its current location to a new location by randomly selecting the speed and direction which are dictated by predefined ranges (Johnson & Maltz, 1996; Lee, Gerla, & Chiang, 1999). Fundamentally the RW paradigm is a mathematical model which formalises the trajectory of a moving node that is taking successive steps. It is strongly correlated to the diffusion models and is essential to the Markov processes. Once the node reaches the new location it pauses then a new speed $(s_{min}, s_{max})_i$ and direction $(0, 2\pi)_i$ parameters are calculated and the node begins the next phase of its journey j_i. This iterates within a given finite period of time and space. The RW tests the movement of nodes around a starting point, without them ever wandering outside the defined boundary. This was proven by Ploya in 1921 who ascertained that the node will return to the starting point with complete certainty (probability of 1.0), cited in (Weisstein, 1998; Daniel, Florian, & Wolfgang, 2011).

The 2-D variation of the RW model is synonymous to the 2-D representation of the Earth's surface. In this model the node commences its movement from the centre of the pre-defined area in the simulation, similar to the first model the node randomly selects the speed and direction to travel, the difference is that the node will travel a specified distance, rather than time before stopping and moving again. The RW Models is a memory-less mobility model, therefore no data is collected to record the previous movement of the node (Liang & Haas, 1999; Hong, Gerla, Pei, & Chiang, 1999), nor is the current trajectory dependent on the previous node's movements, e.g. speed or direction (Hong, Gerla, Peri, & Chiang, 1999). The drawback of this model is that it can produce erratic behaviour such as abrupt stops and quick turns, which are said to be unrealistic in nature (Camp, Boleng, & Davies, 2002). Though if observing a typical teenager on their mobile device walking down the street the randomness of their moment emulates such erratic behaviour consisting of the sudden stops, see figure 2.

Figures 4 to 6, illustrate the movement of multiple mobile nodes utilising the RW algorithm. To place the movement in context the background is to emulate a shopping centre scenario where the public often rely on such technology. These results derived from simulating the RW mobility model in NS3 (NS3, 2011). To accomplish this, the key parameters of the simulation are the area to be traversed, the default area shape is a rectangle, xy, the duration of the walk, t and the distance before recalculating the speed $(s_{min}, s_{max})_i$ and direction $(0, 2\pi)_i$. If the boundary is reached then a recalculation for the rebound angle and speed is invoked. For these simulations the speed is not a random parameter but has been converted to a constant speed to simplify the movement and isolate the randomness of the movement to the path traverse and eliminate the randomness of the speed in the initial stages of the experiments. For the RW mobility model, table 1 illustrates, the parameters used to generate the graphs, the number of mobile nodes recorded are 2,4,8,16,32. In figure 3 you can see two separate unrelated RWs from mobile nodes. Emulating the typical movement of shoppers using their mobile devices, here the pattern of the walk is clear.

In figure 4 and figure 5 you can see as the number of mobile node traces increase there are more intersections of the paths which could result in fiercer competition for a stable connection. By the time 16 mobile node paths have been recorded (figure 4) differentiating between node paths become more difficult. When 32 and above mobile nodes are recorded (figure 5) the paths become almost impossible to differentiate, if this were simultaneous mobile nodes paths in a real-time situation the simulation could be more suited to a large crowded scenario such as a music festival or a busy theme park.

4. RANDOM WAYPOINT

Random waypoint (RWP) mobility model is a common mobility model that is used in the simulation of adhoc wireless networks (Rubin & Choi, 1997; Bar-Noy, Kessler, & Sidi, 1994; Zonoozi & Dassanayake, 1997). In the RWP model, the node initially identifies a random destination which is referred to as the 'waypoint', the actual movement is at a random speed, emulating the RW model (s_{min}, s_{max}). The process commences from a random point in a given space $[x_i, xy_i]$, with the node first pausing [p_i], and then moving toward the pre-defined destination, Figure 6 illustrated expected node movement. Once the node reaches its destination it again pauses before moving to the next pre-defined destination, then the process iterates until it is finally terminated. The key difference between this and the RW model is that it introduces a pause time once the node reaches the pre-defined destination (Johnson & Maltz, 1996). Therefore by setting the pause time to zero the model would emulate the RW model (Camp, Boleng, & Davies, 2002).

Camp, Boleng, Davies, (2002), concluded that this model can produce a variable average neighbour percentage for the first 600 seconds of the simulation resulting in a high variability of the simulation results. If this is an issue for the experiment Camp et al, suggest discarding the first 1000 seconds of the simulation to produce an initial configuration period (Camp, Boleng, & Davies, 2002). To establish if this occurs within the experiments conducted, multiple runs of each simulation will determine if there is any variability in the result produced. Karp and Kung (2000) states that longer pause times will produce a more stable network even at high speeds, as overall this emulates a more static network (Karp & Kung, 2000). The paths of movement produced for both the RW and the RWP simulations are similar, due to the pause parameter not being visual within this graphical type. Therefore only a single node has been illustrated in figure 7, utilizing the same scenario as for the RW model.

5. GAUSS-MARKOV

Gauss-Markov was originally developed for a Personal Communication Service (Liang & Haas, 1999), and more recently incorporated in simulations of ad hoc networks (Camp, Boleng, & Davies, 2002). The Gauss-Markov mobility model uses one parameter to fine tune the levels of randomness of the model from a Gaussian distribution. Each node is allocated its speed and direction which is updated periodically. At each point in time the speed and distance is calculated based on the previous trajectory of speed and direction variables. Any node that lingers by the boundary of the simulated area are actively moved if they are within a pre-defined distance of the boundary.

The Gauss-Markov model reduces the concept of unexpected turns that is fundamental to both the RW and the RWP models, therefore said to emulate a more realistic model of mobility. But as previously acknowledged everyday movement often incorporates unexpected stops, especially if the user is walking while using their mobile device or travelling in a vehicle within a congested city or motorway. The Gauss-Markov model consumes more computational power due to the number of parameters needed to determine the motion of the next step based on the previous position to maintain constant motion. To eliminate abrupt pauses and sudden turns, data needs to be collated from the last move variables to ascertain the future trajectory variables. In equation (1), (Camp, Boleng, & Davies, 2002) you can see how the velocity of the node's trajectory is determined over time. The mean value of v_n is represented by the constant μ. Whereas α is the random tuning parameter 0 ≤ α ≥ 1, setting α=0 to represent Brownian motion and α=1 to represent the linear motion. x_{n-1}.

$$v_n = \alpha v s_{n-1} + (1-\alpha)\mu\alpha\sqrt{1-\alpha^2}\ x_{n-1} \qquad (1)$$

Figure 8 Illustrated a trace of one node moving within the boundary of a 300, 600 (x, y) rectangle that utilizes the Gauss Markov mobility model. As shown, the movement is more fluid with no abrupt stops coupled with sudden turns as evidenced in the other models. To generate the trace the speed and distance changed every second; the next direction and speed of the node is determined via a random gauss variable generated from 1 to 6.28. The use of one node for figure 8 is selected to give clarity to the movement of the model, a trace of multiple nodes distracted from the fluidity of the movement and the elimination of sudden turns becomes unclear.

6. ENVIRONMENTAL EFFECTS ON MOBILITY

This paper will propose a mobility model that has the intention to enhance current synthetic model interaction of nodes with their environment including social factors of movement. This environmental model (EM) will highlight the interaction and correlation between nodes and real world movement. Obstacles are included to replicate real environmental effects on mobility and used as waypoint destinations for nodes, emulating a campus scenario incorporating the realistic movement of MNs using different paths to move around the campus buildings while travelling to their next lecture hall. Figure 9 illustrates the possible angle increments for MN movement, while figure 10 demonstrates the execution of the proposed model when a node (N) is faced with an obstacle impeding its path to its goal (G). When encountering an obstacle realistically humans would not bounce off a building, in the EM nodes repeatedly increment their traversal angle to the nearest 45 degree until they're able to successfully move around an obstacle as shown in figure 10 with the node increasing from 150° to 225°. Upon reaching a goal the node pauses before selecting its next destination see table 2. Similar to the Random Waypoint (RWP) this allows the control of movement of MN, but in this model it also effectively controls the proximity of the nodes to obstacles, the pause parameter can be used to represent the student pause times at buildings as they attend lectures.

7. SOCIAL THEORY EFFECTS ON MOBILITY

Based on the same ideology from social network theory weighted values are assigned to represent the relationships between each node, through an adjacency matrix, with 0.1 being a weak relationship and 0.9 being a strong relationship. These relationships are used for various interactions and affecters of node movement in the model. Interactions between the nodes take the form of 'conversations', which can be initiated when two nodes are in close proximity. The chances of the two nodes pausing is based on the strength of their relationship, a relationship of 0.7 means the nodes will initiate a conversation 7 out of 10 times. Two nodes will pause their traversals for a conversation of a set amount of time again based on the strength of the relationship, the stronger relationship the longer the pause and store the previous node's ID to prevent repeat conversations. From these conversations groups can form, similar to that of social theory, as more nodes will join the conversation.

The node's weighted relationships are used to further integrate social impact by having a node's strong relationships influence its next destination. This is implemented by taking the current destinations of nodes with a high relationship value and adding these current destinations to the next random destination choice of the node thereby biasing the choices. A node is then more likely to choose a destination where it can encounter its friend's thus additional grouping or communities can form. Further to this with each traversal a random number is generated to cause a direct impact on the node's movement by increasing or decreasing its movement angle to a slighter degree. The inclusion of this angle modifier results in a less synthesized human movement than previous models have where nodes traverse in straight lines towards their goal.

8. ENVIRONMENTAL MODEL

The environment is populated with a number of obstacles (*obs*), which are assigned entrances as a list of possible random destinations for all nodes (n), added randomly. Nodes have a relationship with other nodes through an adjacency matrix. Each interval nodes move towards their destinations by calculating the required angle and adding a random angle modifier, by incrementing its angle by 45 until it's possible to move. If another node is in proximity and relationship value is strong then initiate conversation and the pause traversal is invoked. When a node reaches its destination it will pause (*pp*). Then a new destination is selected randomly from a list of potential destinations plus the current destinations of the node's high weighted relationships. The EM and RWP are compared to ascertain the effects on the node mobility. To analyse the models in Repast both scenarios contained 5 nodes with the same set node velocity. Node density was analysed by noting the proximity of the nodes at 30 seconds intervals see figure 12 and the final value is an average of these intervals see figure 13. It can be observed in figure 13 that there is a dramatic increase in the overall closeness of nodes in the EM when compared to the RWP model showing an increased correlation between the interaction of nodes and the overall closeness of nodes. In addition that by increasing the number of obstacles node interactions can be disrupts and their mobility patterns altered. Finally, figure 13 also shows the instability of the node density in the model, pointing to the formation of groups of nodes at random periods within the simulation.

9. SUMMARY

These models are not without their faults, the RW model requires the spatial distribution of the node which is non-uniform (Bettstetter, Resta, & Santi, 2003). Also there is decay in the speed when nodes are undertaking extended periods of mobility (Yoon, Liu, & Noble, 2003). as generally mobile device users do not walk in a uniform fashion with equal spatial distribution nor at a uniform speed.

The RW Mobility model that utilizes small parameters for the distance or the duration of the movement will produce a Brownian motion with minimal movement. Substantially increasing the parameter replicates a RWP without a pause. This model has been used in many prominent simulation studies of ad hoc network protocols (Camp, Boleng, & Davies, 2002; Hong, Gerla, Pei, & Chiang, 1999; Lee & Hou, 2006). The model has some flexibility built into it and can replicate a certain level of reality of node movement. Though the key issue is that it assumes all movement is in a straight line pattern between destinations. The Gauss-Markov model also has the ability to replicate real-world patterns of movement though the parameters need to be carefully selected to produce this.

Camp et al (2002) recommend the use of either the RWP or RW mobility models if an entity mobility model is required. Key indicator to this decision is the availability of the models within the simulation packages and that with a few shortcomings mobility of the real-world to an expectable level is replicated (Camp, Boleng, & Davies, 2002). The results shown in figure 3 to 8 agree with camp et al (2002), recommendation, both models can emulate movement which typifies mobile users in an ad hoc network. The EM overcomes this limitation by encompassing social and environmental factors into the simulation. The constraint of this model is that social connection and destination needs to be known before commencing the simulation and it too adds more computational requirements to the process.

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Table 1. Parameters used in the simulations for the Random Walk mobility model

Parameter	**Value**
Time (t)	10
Speed (S_{min},S_{max})	Converted to a constant speed of 15
Direction(0,2π)	0.0, 0.628
Area (x,y)	(0|6000)(0|6000)
Starting Position	(0|100)(0|100)
Total Simulation time	100
Mode	Time

Table 2: An Example of an Adjacency Relationship Matrix between 5 nodes

	1	**2**	**3**	**4**	**5**
1		*0.3*	*0.7*	*0.9*	*0.1*
2	*0.3*		*0.4*	*0.2*	*0.8*
3	*0.7*	*0.4*		*0.6*	*0.1*
4	*0.9*	*0.2*	*0.6*		*0.4*
5	*0.1*	*0.8*	*0.1*	*0.4*	

FIGURES

Figure 1. An illustration of the random wiggling behaviour of pollen grain in water.

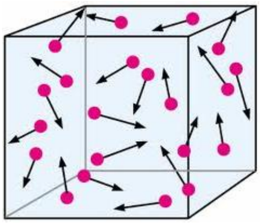


Figure 2. Route of a Typical Mobile Device User

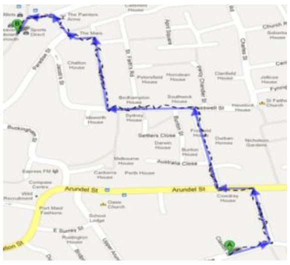


Figure 3. Random Walk Mobility Model Simulating Two Nodes

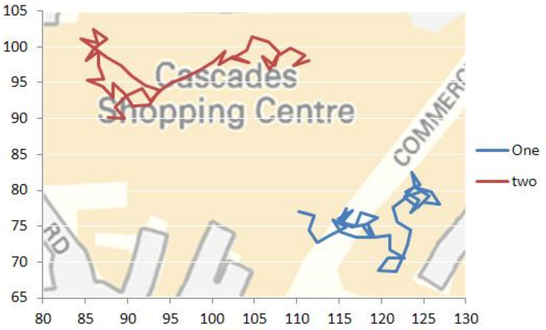


Figure 4. Random Walk Mobility Model Simulating Sixteen Nodes

Figure 5. Random Walk Mobility Model Simulating Thirty Two Nodes

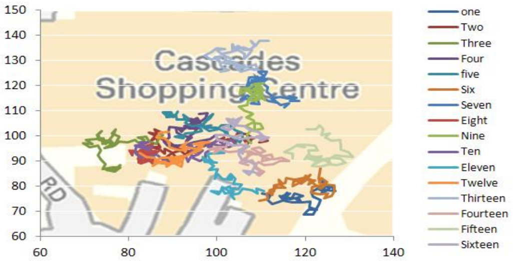


Figure 6. Typical Movement Produce for the Random Waypoint

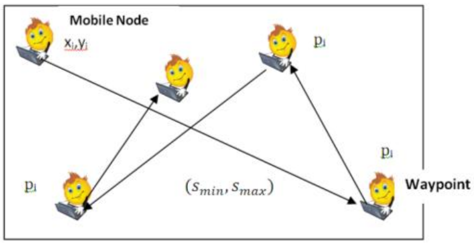


Figure 7. Single Node Mobility using the Random Waypoint Model

Figure 8. A One Node Trace of a Mobile Node using the Gauss-Markov Mobility Model.

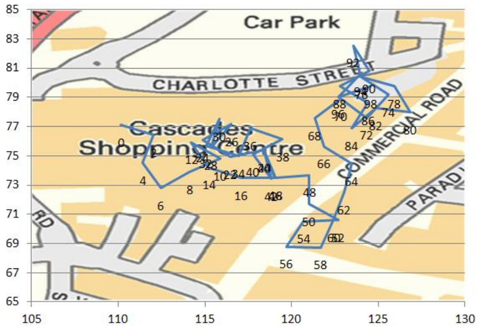


Figure 9. The possible angle increments for movement

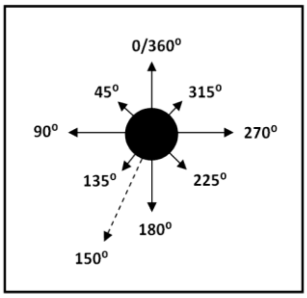


Figure 11. A screenshot of the proposed model running with 5 nodes and 5 obstacles in the Repast software with noted node densities

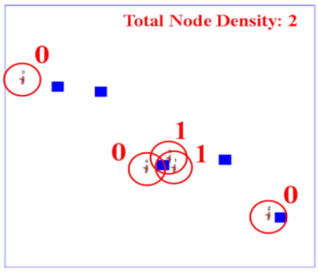
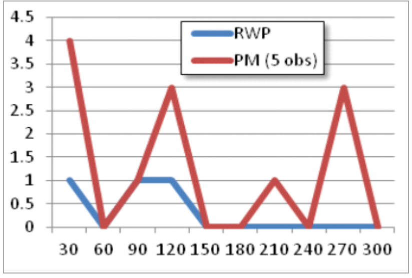


Figure 13. The node density values for RWP and the proposed model with 5 obstacles.



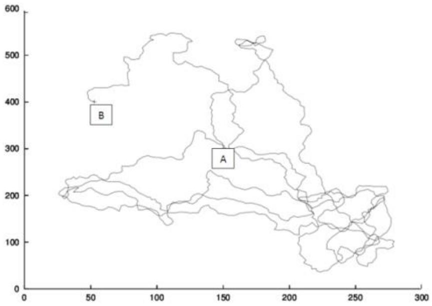


Figure 10. Implementation of the proposed model when a node (N) is faced with an obstacle impeding its desired path to its goal (G)

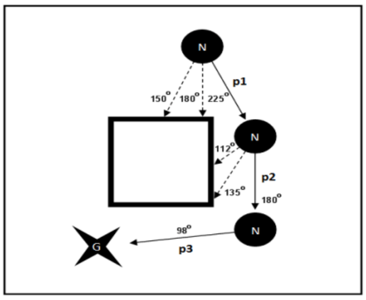


Figure 12. The average node densities of RWP and the proposed model with a varying number of obstacles