**KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI**

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# COMPARATIVE STUDY OF PREDICTIVE MOBILITY MODELS FOR MANETS BY SIMULATION

**BY**

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## DECLARATION

I hereby declare that, except for specific references which have been duly acknowledged, this work is the result of my own research and it has not been submitted either in part or whole for any other degree elsewhere.

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# ABSTRACT

Mobile Ad hoc Networks (MANETs) are dynamic networks populated by mobile stations or mobile nodes (MNs). Specifically, MANETs consist of a collection of nodes randomly placed in a line (not necessarily straight). MANETs do appear in many real-world network applications such as a vehicular MANETs built along a highway in a city environment or people in a particular location. MNs in MANETs are usually laptops, PDAs or mobile phones. These devices may use Bluetooth and/or IEEE 802.11 (Wi-Fi) network interfaces and communicate in a decentralized manner. Mobility is a key feature of MANETs. Each node may work as a router and the network can dynamically change with time; when new nodes can join, and other nodes can leave the network.

In this thesis, comparative results of the Queueing Mobility Model and mobility models such as random walk/Brownian model have been carried out via Matlab software simulation. The study investigates the impact of mobility prediction models on mobile nodes' parameters such as the speed, the arrival rate and the size of mobile nodes in a given area. The results have indicated that mobile nodes' arrival rates may have influence on MNs population (as a larger number) in a location. An initial position of nodes has appeared to have a significant effect on their movement pattern (trajectory). The Pareto distribution is more reflective of the modeling mobility for MANETs than the Poisson distribution.

**Keywords:** Mobility Models, MANETs, Pareto, Simulation, Poisson Distribution, Arrival Patterns.

## DEDICATION

To Almighty God

My loving wife & children

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May everyone who in diverse ways has contributed to the success of this project, find my sincere appreciation.

And may God richly bless you all…

# LIST OF ABBREVIATIONS

MANETs - A Mobile Ad hoc Networks

PANs - Personnel Area Networks

ADHNet - ad hoc network

PDAs - Personal Digital Assistants

pdf – Probability Density Function

PDF – Probability Distribution Function

MNs – Mobile Nodes

User/Mobile device – Node or MN

QMM – Queueing Mobility Model

iid - Independent and identically distributed

M/M/1 – The M/M/1 notation implies:
– A single server queue
– Exponentially distributed inter-arrival times
– Exponentially distributed service times.
– Infinite population of potential nodes

M – Memoryless or Exponential

RMM - Random Mobility Model

RWM – Random Walk Mobility

RM – Random Motion

St – Service Time

N – Number of Nodes

Lambda – Arrival rate

Mu – Departure Rate

S – Speed

T – Time

Iat – Inter-arrival Time

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# CHAPTER 1: INTRODUCTION

## 1.0. Background (Overview of MANETs)

Mobile Ad-hoc NETworks (*MANETs)* is a collection of wireless mobile nodes configured to communicate amongst each other without the aid of an existing infrastructure. MANETS are *Multi-Hop* wireless networks since one node may not be indirect communication range of other nodes. In such cases the data from the original sender has to travel a number of hops (hop is one communication link) in order to reach the destination. The intermediate nodes act as routers and forward the data packets till the destination is reached [1, 30].

Like other networks the performance of ad hoc networks is affected by its topology. However, in ad-hoc networks the role of topology becomes more critical due to nodes' mobility [1, 2]. Consequently, many simulation tools are being used for ad hoc networks studies with help of mathematical models known as *mobility models* to generate various kinds of network topologies. It is important to recall that Mobility models should be able to mimic the distribution and movement pattern of nodes as in real-life scenarios. Many researchers have proposed indigenously mobility models (Random Walk, Random Waypoint [3, 4]) for performance comparison of various routing protocols. The concern with indigenously designed models is that they represent a specific scenarios not often found in real lives. Hence their use in ad hoc network studies is very limited. Random Walk or Random Waypoint model though simple and elegant, produce random source of entry into a location with scattered pattern around the simulation area. In real-life, this may not really be the case. The initial entry point and distribution of a *Mobile Node (MN)* may be far random and may be influenced by various factors (time of day, traffic conditions, weather conditions, rescue mission, and so on).

Ad hoc networks are viewed to be suitable for all situations in which a temporary communication is desired. The technology was initially developed keeping in mind the military applications [5] such as battlefield in an unknown territory where an infrastructured network is almost impossible to have or maintain. In such situations, the ad hoc networks having self-organizing [9, 30] capability can be effectively used where other technologies either fail or cannot be effectively deployed. The entire network is mobile, and the individual terminals are allowed to move freely. Since, the nodes are mobile; the network topology is thus dynamic. This leads to frequent and unpredictable connectivity changes. In this dynamic topology, some pairs of terminals may not be able to communicate directly with each other and have to rely on some other terminals so that the messages are being delivered to their destinations. Such networks are often referred to as multi-hops or store-and-forward networks [11, 30]. An illustration is shown in Figures 1.1 and 1.2.

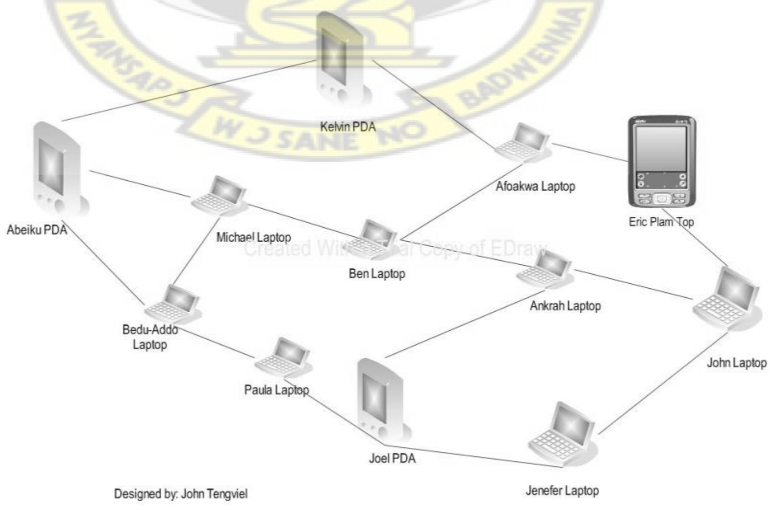


**Figure 1.1: MSC Telecommunication Engineering Students Sharing Information**

**Figure 1. 2: Heterogeneous Devices**

Figure 1.1 shows an example of an ad hoc network which has different communication devices and some connections amongst them; in which the MSC *students were to do a group work/discussion on campus.* The students came in the area and without the need of any existing infrastructure, switch on their handsets, laptops or PDAs that enable them to communicate with each other while moving and carrying out their work from one office to another office or one floor to another. In this case of group work, an ad hoc network has been formed by the communication devices.

## 1.1 Application Areas of MANETS

The rapid development of wireless communication and mobile terminals, such as PDA, mobile phones, laptops, pocket PC, and some other communication devices based on wireless, infrared, and so on; have shown great applications for mobile ad'hoc networks [5 - 8]. Compared with cellular wireless networks, Ad Hoc networks have no base station. All the MNs in Ad Hoc networks not only are transceivers, but also have the router function [4]. At present, Ad Hoc networks have become one of the hot research focuses [9]. Few of recent areas of study are:

• Digital Military Battlefield. MANETs are often used in battlefield to allow soldiers, their vehicles and centers to maintain information exchange among them. The main reasons behind it is the fact that military equipment routinely contains computer related equipment to which the MANETs techniques can be applied. The characteristics of information are of great importance for the military and since MANETs do not need a structured system, they find great use in their survivable.

• Disaster Management. Speedily deployable of MANETs and other wireless communication technology such as cellular networks can be used in decentralised disaster management communication networks. These kind of networks can be very useful in rescue operations for disaster relief efforts where the entire or part of communication infrastructure is destroyed and restoring communication network is very crucial for people's lives and their properties.

• Personal Area Networks (PANs). MANETs, as other personalisation technologies, allows interconnection of mobile devices such as PDAs and laptops through short radio ranges. PAN has got a number of applications including enabling devices to unconventionally detect and acquire one another within allowable radio range. The foremost advantage of PANs is that they do not only rely on infrastructured network to allow the users to form a MANETs.

• Automotive Networks. These networks will facilitate users and their vehicles to automatically form MANETs of different sizes while traveling on the roads. This application will allow information exchange among users on road conditions such as traffic congestions and accident warnings.

Besides their attractive applications MANETs have a number of challenges that need to be studied carefully.

## 1.2 Properties/Characteristics of Mobile Ad hoc Networks

MANETs have the following special features [6, 7, 8] that should be considered in designing:

• **Dynamic Topology - T**he node mobility, the topology of mobile multi-hop ad hoc networks changes continuously and unpredictably. The link connectivity among the terminals of the network dynamically varies in an arbitrary manner and is based on the proximity of one node to another node. It is also subjected to frequent disconnection during node's mobility. MANETs should adapt to the traffic and propagation conditions as well as to the mobility patterns of the mobile network nodes. The mobile nodes in the network dynamically establish routing among themselves as they move about, forming their own network on the fly. Moreover, a user in the MANETs may not only operate within the ad hoc network, but may require access to a public fixed network.

• **Bandwidth -** MANETs have significantly lower bandwidth capacity in comparison with fixed networks. The used of air interface has higher bit error rates, which aggravates the expected link quality. Current technologies suitable for the realization of MANETs are IEEE 802.11(b,a) with bandwidth up to 54Mbps and Bluetooth providing bandwidth of 1Mbps. The nature of high bit-error rates of wireless connection might be more profound in a MANETs. One end-to-end path can be shared by several sessions. The channel over which the terminals communicate is subjected to noise, fading and interference, and has less bandwidth than a wired network. In some scenarios, the path between any pair of users can traverse multiple wireless links and the links themselves can be heterogeneous.

• **Energy -** All mobile devices will get their energy from batteries, which is a scarce resource. Therefore the energy conservation plays an important role in MANETs. This important resource has to be used very efficiently. One of the most important system design criteria for optimization may be energy conservation.

• **Security -** The nodes and the information in MANETs are exposed to the same threats like in other networks. Additionally to these classical threats, in MANETs there are special threats, e.g. denial of service attacks. Also mobility implies higher security risks than static operation because portable devices may be stolen or their traffic may insecurely cross wireless links. Eavesdropping, spoofing and denial of service attacks should be considered.

• **Autonomous -** No centralized administration entity is required to manage the operation of the different mobile nodes. In MANETs, each mobile terminal is an autonomous node, which may function as both a host and a router. So usually endpoints and switches are indistinguishable in MANETs.

• **Distributed Operation -** Since there is no background network for the central control of the network operations, the control and management of the network is distributed among the terminals. The nodes involved in a MANETs should collaborate among themselves and each node acts as a relay as needed, to implement functions e.g. security and routing.

• **Multi-hop Routing -** Basic types of ad hoc routing algorithms can be single-hop and multi-hop, based on different link layer attributes and routing protocols. Single-hop MANETs is simple in comparison with multi-hop MANETs in terms of structures and implementation. When delivering data packets from a source to its destination out of the direct wireless transmission range, the packets should be forwarded via one or more intermediate nodes.

## 1.3. Motivation

A majority of the previous studies on MANETs concentrated on energy utilization, throughput, scalability and packet drop rate in an idealistic environment [10], without giving much importance to the need of realistic mobility. Many researches in MANETs depend mainly on simulations since real-world test-beds consisting of large number of nodes are infeasible [1]. It is crucial that the mobility models employed for these simulations are able to illustrate the behaviour of MNs in a realistic way. Different mobility models have been proposed by the research community for this purpose [1]. However, a lot needs to be done especially in the area of mobility modeling, whereas majority of current research in MANETs assumes that the nodes are uniformly randomly placed over the system area. Such a homogeneous initial point of entry is convenient in the network simulations. In real networks, however, the nodes are in general not uniformly distributed initially but have a common source of entry or exit. We therefore model the nodes initial entry point by designing inhomogeneous node placement for both QMM and RWM. We also considered the important properties of the resulting distribution as the simulation progresses, as well as the probability density of the arrival patterns of the MNs.

## 1.4 Objectives

The work in this thesis performs an in-depth study on the queueing mobility model in MANETs with emphasis of defining a common source point of mobile nodes. This approach is similar to adopted strategy in a disaster zone such as what happen in Haiti or Chile recently and others that nodes move in line.

The thesis aims to analyse a comparative analysis of the Queueing Mobility Models by statistical means and simulation using MatLab software. The work introduces a common entry/initial inhomogeneity of the MNs, the number of MNs on speeds arrival rates on the number of MNs and arrival rates on nodes distributions. The following areas are being explored:

- an analysis of mobility model parameters using the statistical distributions.
- a comparison of the new mobility model with common mobility models such as Random walk.
- a development of a set of metrics for node mobility.

## 1.5 Organisation of the Thesis

The remaining of the thesis has the following structure; the Chapter 2 presents review of related work in the area of mobility models as well as Pareto and Poisson distributions. In Chapter 3 we describe the simulation details, providing detailed discussion on the parameters, and a description of the simulation algorithms. Chapter 4 presents the results of our simulation, interprete the results, and discuss the associated implementations to queueing mobility model. Finally Chapter 5 concludes/summaries the results and direction we would like to take this work in the future.

## 1.6 Conclusion

A Mobile Ad hoc Networks (MANETs) is a self-configuring (autonomous) system of mobile routers (and associated hosts) connected by wireless links -the union of which form an arbitrary topology. The routers are free to move randomly and organize themselves arbitrarily; thus, the network's wireless topology may change rapidly and unpredictably. This chapter has illustrated the background of the MANETs, the study's motivation, objectives, and structure. In the next chapter we are going to review the theory behind mobility models of MANETs including queueing models.

# CHAPTER 2: LITERATURE REVIEW

## 2.0. Introduction

The study of Ad hoc network seem to be centered around the user mobility. Mobility models are mainly used to describe the movement of nodes, so they play a key part in simulating ad hoc networks [1, 9]. Nodes operate in real-life situations. The user or any mobile device is modeled as a node.

In this chapter a review of ADHNets theory, queueing theory and also mobility models in MANETs are underlined.



## 2.1. Mobility Models For Ad Hoc Networks

The MANETs models' study in [10-12], has shown that currently there are two types of mobility models used in simulation of networks. These are traces and synthetic models. Traces are those mobility patterns that are observed in real-life systems. Traces provide accurate information, especially when they involve a large number of mobile nodes (MNs) and appropriate long observation period. On the other hand, synthetic models attempt to realistically represent the behaviour of MNs without the use of traces. They are divided into two categories, entity mobility models and group mobility models [1, 13, 14]. The entity mobility models randomise the movements of each individual node and represent MNs whose movements are independent of each other. However, the group mobility models are a set of groups' nodes that stay close to each other and then randomise the movements of the group and represent MNs whose movements are dependent on each other. The node positions may also vary randomly around the group reference point. In [15], the mobility study in ad hoc has been approximated to pedestrian in the street, willing to exchange content (multimedia files, mp3, etc.) with their handset whilst walking at a relative low speed. All pedestrians have been assumed to be within a predefine range of communication and do not collide with each other as it is a case in a dense network. The semi-analytic study has shown that it is possible for communication devices in urban areas to be made up of an efficient MANETs where they work and efficiently share content through a unique server.

### 2.1.1. Random Walk Mobility

The Random Mobility Model (RMM) for ad'hoc networks is the Random Walk/ Brownian Mobility Model used in cellular networks. In this modeling the current speed and direction of a Mobile Node (MN) is independent of its past speed and direction [5, 16, 17]. Thus, we encounter an unrealistic generation of movements such as sudden stopping, sharp turning, and completely random wandering. Due to these difficulties, many authors modify the Random Mobility Model by changing the calculation of speed, direction, or both. The random walk mobility (RWM) model is defined by Camp et al [1], as an erratic movement. This might appear quite very difficult to predict. It is a memoryless movement whose previous speeds and directions are unknown. This property produces a simple mathematical mobility model which makes use of Markov processes and chains, with a generalised unrealistic approach in user's movement. The node position is modeled with a random speed (V) and direction (θ). Both of them are chosen from predefined ranges. The speed is defined in the range of a minimum speed (Vmin) and maximum speed (Vmax) and written as [Vmin,Vmax] having a direction [0, 2$\pi$]. Each movement has a constant duration or a constant distance travelled.

### 2.1.2. Random Waypoint Mobility Model

The Random Waypoint Mobility (RWM) includes pause times between changes in direction and/or speed [1, 2, 11, 18]. MN begins by staying in one location for a certain period of time known as a pause time which is not available in the previous models. Once this time expires, the MN chooses a random destination with a speed that is uniformly distributed over the range [0, Vmax]. It travels towards the newly chosen destination at the selected speed. Upon arrival, the MN takes another break (pause) before starting the process again. Many authors [1] adopted this model in their simulation studies including slightly modified Random Waypoint Mobility Model so that MN travels at a constant speed throughout the entire simulation. This model is a memoryless, and has the same limitation as the random mobility model.

### 2.1.3 Probabilistic Version of the Random Mobility Model

In [2, 19], the mobility model utilizes a probability matrix to determine the position of a particular MN in the next time step. The probability matrix takes into account three different states. These states are: State 0 represents the current location of a given MN, state 1 represents the MN's previous location, and state 2 represents the MN's next location if the MN move forward. The probability matrix is written as:

$$P = \begin{bmatrix} P(0,0) & P(0,1) & P(0,2) \\ P(1,0) & P(1,1) & P(1,2) \\ P(2,0) & P(2,1) & P(2,2) \end{bmatrix}$$

Where each entry P(a,b) represents the probability that an MN will go from **state A** to **state B**. In [2, 19], Chiang's simulator uses each node that moves randomly with a preset average speed. The values use to calculate x and y movements are given as:

$$P_1 = \begin{bmatrix} 0 & 0.5 & 0.5 \\ 0.3 & 0.7 & 0 \\ 0.3 & 0 & 0.7 \end{bmatrix}$$

Where, x is the horizontal movement and y is the vertical movement.

Probability matrix **P1** allows an MN to move in any direction as long as it does not return to its previous position. This implementation produces a probabilistic movement rather than purely random movements, thus yields more realistic behaviour. For example, as people complete their daily tasks they tend to continue moving in a semi-constant forward direction. Authors in [2] have argued that rarely we do unexpected turn around to retrace our steps and almost never take random steps hoping that we eventually wind up somewhere relevant to our tasks. However, choosing appropriate values of P($a$, $b$) may seem difficult, if not impossible.

## 2.2. Group Mobility Model

Group mobility models represent multiple MNs having a total or partial action dependent on one another [2]. However, in many real situations, it is necessary to model the behavior of MNs that move together. For example, many military scenarios occur where a group of soldiers must collectively search a particular plot of land in order to destroy land mines, capture enemy attackers, or simply work together in a cooperative manner to accomplish a common goal [1, 2, 18, 19]. In such situations, group mobility model need to account for new cooperative characteristics.

Some of the mobility models account for dependencies resulting from the interactions between MNs such as the Reference Points Group Mobility Model. A model that represents random motion of a MNs group or a random motion of each individual MN within a group.

### 2.2.1. Simple Group Mobility Models by Sanchez

Sanchez et al [20] have noted that a random walk/random movement model may not be sufficient to describe many "real-life" situations. Typically, the model may account for dependencies resulting from the interactions between MNs. These interactions have been considered in Pursue Model, and Nomadic Community Mobility Model [1, 2, 16, 19, 20].

### 2.2.2. Pursue Mobility Model

The Pursue Mobility Model is also defined in [1, 2, 16, 19, 20]. As the name implies, the Pursue Mobility Model attempts to represent MNs tracking a particular target. For example, this model could represent police officers attempting to catch an escaped criminal. The Pursue Mobility Model consists of a single update equation for the new position of each MN:

*new position* = *old position* + *acceleration*(*target* - *old position*) + *random vector*

where *acceleration(target - old position)* is information on the movement of the MN being pursued and *random vector* is a random offset for each MN. The *random vector* value is obtained via an entity mobility model (e.g., the Random Walk Mobility Model); the amount of randomness for each MN is limited in order to maintain effective tracking of the MN being pursued. The current position of an MN, a random vector, and an acceleration function are combined to calculate the next position of the MN.

### 2.2.3. Group and Partition Prediction in Mobile Ad-hoc Networks

In wireless ad hoc networks, network partitioning occurs when mobile nodes moving with diverse mobility patterns cause the network to separate into two disconnected entities. As global scale changes in topology are attributed to group mobility, a method of partition prediction in [21] that exploits group mobility patterns was proposed. If the network consists of two mobility groups and each moving at different velocity, their relative mobility is obtained by fixing one group stationary. In a network made up of diverse mobility groups given the mean group velocity, the time of separation can be calculated for any pair of mobility groups. The occurrence of partitioning is predicted as a sequence of expected time of separations between the various mobility groups in the network. The partition prediction method employed in a clustering algorithm exhibits prefect accuracy of the node classification; however group and node velocities are considered to be time invariant, which is not typical of ad hoc networks.

The mobility model is a simple and abstract mathematical description for the real mobile scene to simulate the rule of nodes' mobility in Ad Hoc network, which could evaluate the influence of node' mobility on the performance of Ad Hoc network.

## 2.3. Queueing Modeling Theory

Queueing theory is an intricate and yet highly practical field of mathematical study that has vast applications in performance evaluation [22]. A queueing system is a place where nodes arrive according to an 'arrival process' to obtain service from service facility. The service facility may contain more than one server, and it is assumed that a server can serve one node at a time. If arriving nodes finds all servers occupied, it joins a waiting queue. These nodes would later receive their services and then leave the system upon completion of the services. The queueing mobility models are next discussed with regard to their arrival pattern.

### 2.3.1. The Arrival Pattern

The arrival pattern means both the average rate of nodes and the statistical pattern of the arrivals. Generally, the arrival process is described in terms of the probability distribution of the interval between consecutive arrivals.

Let A(t) denotes the probability density function of arrival pattern distribution then: A(t) = P[time between arrivals <t].

Depending on the arrival rate in the process, the probability function distribution will bear the name that describes its arrival rate parameter. Thus in literature, we therefore have regular and completely random arrival [22 - 25].

### 2.3.1.1 Regular Arrival

The simplest arrival pattern physically is the regular one in which nodes arrive simply at equally spaced instants, T units of time apart. The rate of arrival of nodes is $\lambda = 1/T$ per unit time.

### 2.3.1.2 Completely Random Arrivals

The arrivals are described by their statistical arrival distribution, which can be specified as follows:

#### A. Arrivals Per Unit of Time



The simplest arrival pattern mathematically and the most commonly used in all applications of queueing theory is completely random arrival process. To define this process formally, the arrival distribution is specified in the first way, the number of arrivals that can occur in any given period of time must be described. When arrivals occur at random, the information of interest is the probability of $n$ arrivals in a given time period, where $n = 0, 1, 2, \ldots\ldots n-1$

Let $\lambda$ be a constant representing the average rate of arrival of nodes and consider a small time interval $\Delta t$, with $\Delta t \rightarrow 0$. The assumptions for this process are as follows:

- The probability of one arrival in an interval of $\Delta t$ seconds, say **(t, t+Δt)** is $\lambda\Delta t$, independent of arrivals in any time interval not overlapping **(t, t+Δt).**
- The probability of no arrivals in $\Delta t$ seconds is $1-\lambda\Delta t$, under such conditions, it can be shown that the probability of exactly **n** nodes arriving during an interval of length of **t** is given by the Poisson distribution law in equation 2.1:

$$\mathbf{P(n)} = \frac{(\lambda t)^n e^{-\lambda t}}{n!}, \quad \text{where } n \geq 0,\ t > 0 \qquad 2.1$$

Where:

$P(n)$ = probability of having n MNs arrive in time t,

***t*** = duration of the time interval over which MNs are counted,

**λ** = average MN flow or arrival rate, and

***e*** = base of the natural logarithm (***e* = 2.718**).

The assumption of Poisson MN arrivals also implies a distribution of the time intervals between the arrivals of successive MN in a location, $\tau$, being greater than or equal to the time interval *t*, so from Equation. 2.1:

$$\mathbf{P(0) = P[\tau > t] = e^{-\lambda t}} \qquad \textbf{2.2}$$

This MNs distribution in a location is known as the negative exponential distribution and is often simply referred to as the exponential distribution.

## B. Inter-arrival Time or Exponential Distribution

This method of arrival specifies the time between arrivals. In this case one indicates the probability distribution of a continuous random variable which measures the time from one arrival to the next. If the arrivals follow a Poisson distribution, it can be shown mathematically that the interarrival time will be distributed according to the exponential distribution.

Let assume, if $P[t_n>t]$ is just the probability that no arrivals occur in (0, t), that is $P_0(t)$. Therefore, we have $A(t) = 1 - P_0(t)$. That is the Probability Distribution Function [PDF] is given as in equation 2.3.

$$A(t) = 1 - e^{-\lambda t} \text{ Or } PDF[A(t)] = 1 - e^{-\lambda t},\ t \geq 0 \qquad 2.3$$

and its probability density function (pdf) is given by the equation 2.4.

$$f(t) = \frac{\partial A(t)}{\partial t} = \lambda e^{-\lambda t},\ t \geq 0 \qquad 2.4$$

### C. Pareto Arrival Rate on Probability Distribution

The node arrival times of the Pareto distribution [27, 28] are independent and identically distributed, which means that each arrival time has the same probability distribution as the other arrival times and all are mutually independent. The two main parameters of the Pareto process are the shape $\alpha$ and the scale parameter (x).

For one parameter Pareto ($\alpha$ shape only), the distribution function can be written as:

$$F(X) = 1 - \left(\frac{1}{1+X}\right)^{\alpha}, X \geq 0 \qquad 2.5$$



The pdf is given as:

$$f(X) = \frac{\alpha}{(1+X)^{\alpha+1}} \qquad 2.6$$

and for the two – parameter Pareto distribution function defined over the real numbers can be written as:

$$F(X) = 1 - \left(\frac{1}{\alpha+X}\right)^{\beta}, \text{ with } \begin{cases} X \geq 0 \\ \alpha, \beta > 0 \end{cases} \qquad 2.7$$

Its pdf is given as follows:

$$f(X) = \frac{\alpha}{\beta} * \left(\frac{\beta}{X}\right)^{\alpha} \qquad 2.8$$

## 2.4. Mobiles' Node Speed Correlation

A metric of investigating node mobility is the speed correlation $Cor_{MNspeed}$. For a given different time $t$ and $t + \Delta t$ a temporal dependence degree is assumed between two mobiles nodes in motion with speed $\overrightarrow{v_1}$ and $\overrightarrow{v_2}$. The speed correlation $Cor_{MNspeed}$ can be expressed as in [29] and given by equation 2.9:

$$Cor_{MNspeed} = \frac{\overrightarrow{v_1} * \overrightarrow{v_2}}{\|\overrightarrow{v_1}\| * \|\overrightarrow{v_2}\|} * \frac{\|\overrightarrow{v_1}(t+\Delta t)\|}{\|\overrightarrow{v_2}\|} \qquad 2.9$$

It may also be admitted that the speed correlation is not effective to describe node mobility modeling, since the movement of nodes is not uniform over a given area as well as in simulation works. It is suggested in [29] that a reliable mobility node model should minimizes the distance between nodes. We also recall a clustering coefficient of nodes and assume that as in real-world, group has impact on individuals. The clustering coefficient as proposed by Watts & Stogatz is a metric used to discriminate mobility models. The clustering coefficient is the ratio of the radio links among neighbours and the number of neighbours' nodes. This clustering coefficient is related to the network redundancy and is calculated as: Let $N_{MN}$ be the set of neighbors of the node $MN$ and $N_v$ the total number of nodes. The clustering coefficient $Clust_{coeff}$ is defined as:

$$Clust_{coeff} = \frac{\sum_{v \in N_{MN}} |\{x \in N_v\}|}{N_{MN}} \qquad 2.10$$

Consequently, $Clust_{coeff}$ states that if a node presents a high clustering coefficient, this means that the neighboured nodes have more radio links. The control over the clustering coefficient and node speed correlation may highly improve the routing performance but though this is not the concern in the study of modeling mobile node mobility. In this work, we assume that over a given area with following hypothesis:

If we let $d$ be the maximum distance between Nodes, let $\Delta x$ be a dimensionless displacement which corresponds to time difference $\Delta t$ such that:

If $\Delta x < d$ then $\lambda$ may be assumed to follow Poisson arrival rate

If $\Delta x > d$, the MN moves out of the given area then $\lambda$ may be assumed to follow Pareto arrival rate.

Hence, we can define a factor of correlation distance $Cor_{dist}$ between nodes as:

$$Cor_{dist} = k * \sum \frac{\|d(t),\ d(t+\Delta t)\|}{\|d\|} \qquad 2.11$$

K is a parameter which is related to the total number of nodes and the node speed of arrival.

## 2.5. Conclusion

In MANETs user movement has some degree of regular and irregular patterns. However, the node's current and past mobility pattern can provide useful information that can be used to anticipate the node's future location. Purely random mobility model such as the memory-less random walk model and random waypoint are not very suitable for modeling node mobility in MANETs as was also observed by *Davies et al* in [1 19] during their investigation on mobility models for Ad hoc network. In this chapter we considered the literature review of mobility models and review known queueing theory. The next chapter describes the simulation details, by providing detailed discussion on the parameters, the simulation methods employed, algorithms and flowcharts.

# CHAPTER 3: METHODOLOGY

## 3.0. Introduction

Mobile Ad-hoc NETworks (*MANETs)* is a collection of wireless mobile nodes configured to communicate amongst each other without the aid of an existing infrastructure. Often researchers employ indigenously existing models on mobility for performance comparison of various protocols. In the study of MANETs performance, many simulation tools are also used. These tools are simulation software packages that employ mathematical models such as mobility models to generate various kinds of network topologies. It may be admitted that simulation results are faster than conducting experimental study which is time consuming and expensive.

## 3.1. Research Statement

This thesis aims to give a comparative study through simulation in Matlab software, the performance of mobility models with regard to MNs arrival patterns. The MNs arrival pattern are being considered to follow Pareto and Poisson distributions.

The work will justify the better of the arrival patterns on one hand when implementing the MANETs in Ghana where the telecommunication infrastructures are not sufficiently in place, and on the other hand the data demand is also increasing whereas the voice activity remains pertinent.

## 3.2. Queueing System

The queueing system can be described as in Figure 3.1. by the following characteristics:

i. Arriving Nodes: this is specified by the distribution of inter-arrivals time of nodes, that is arrival patterns

ii. Exiting Nodes: it is specified by the distribution of the time taken to complete service, which is assume to be departures

iii. Server: It has a single server or location

iv. Input Source: The number of nodes that arrive in the service facility

v. Queueing Discipline: The first – comes – first serves (FCFS) is assumed as the service discipline.


**Figure 3 1: M/M/1 Queueing System Model**

The Queueing Theory Model allows probabilistic predictions of the MNs movement. The system model can also be illustrated as in Figure 3.1. The Assumptions on the mobile nodes and the network in this study are:

- Independent and identically distributed (IID) - Stationary (Time homogeneity),
- The system (location) consists of a set of n independent MNs communicating over a wireless network.
- All communication links are bidirectional i.e., all nodes have the same transmission range.

## 3.3. Simulation Tools and Considerations

The section deals with the simulations in order to study the performance indicators of the queueing mobility model. A brief description of the simulation environment, the metrices collected and the various simulations perform follows. The computer program (or simulation) was run with several random values and the modeled behaviours were recorded for analysis and displayed in form of snapshots.

### 3.3.1. MATrix LABoratory (MATLAB) Simulator

The simulations have been carried out by using MatLab [26]. Matlab is developed by MathsWorks. It is commercially available. It is a high performance language for technical computing mostly used by engineers and researchers. It can be integrated to oriented languages as C++, and contains a variety of tools capable of computation and mathematical modeling, algorithm development and analysis, modeling and simulation, data analysis etc. Hardware and operating system (OS) configurations for performing simulations were specified as in Table 3.1

**Table 3 1: Hardware and Software Configuration**

| | |
|---|---|
| Processor | Pentium D, CPU 3GHz |
| RAM | 8GB |
| Hard Drive | 350GB |
| Operating System (OS) | Windows Vista/7 |
| MatLab | 8 |

### 3.3.2. Algorithm

The majority of current research in MANETs assumes that the nodes are uniformly randomly placed over the system area. Such a homogeneous initial point of entry is convenient in the network simulations. In real networks, however, the nodes are in general not uniformly distributed initially but have a common source of entry or exit. We therefore model the nodes initial entry point by designing inhomogeneous node placement for both QMM and RWMM. We also considered the important properties of the resulting distribution as the simulation progresses, as well as the probability density of the arrival patterns of the MNs.

The section also considered the algorithms and flowcharts for the simulation presented. The QMM uses arrival and departure rates to calculate the queue mobility part from time t to time t+1, which also include the RM component. The new position for each MN is then calculated by summing the random motion with the new queueing mobility. Below are the algorithms and flowcharts for the simulation of both QMM and Random walk model.

Algorithm for QMM

Step1. Start

Step2. Read N, lambda, mu, st, s, t

Step3. I = 0

Step4. R = rand(n, 1)

Step5. Iat = -1/lambda * log(r)



Step6. X = zeros(n, 1)

Step5. Y = zeros(n, 1)

Step6. X(1) = iat(1)

Step7. x(i) = x(i-1)+ iat(i)

Step9. Y = -1/mu * log(r)

Step10. Y(1) = X(1) + st(1)

Step11. Y(i) = max(x(i) + st(i), y(i-1) + st(i))

Step8. I = i+1

Step12. If i<=n then go to 7

Step13. Plot x, y

Step14. While I < t

Step15. Drawnow

Step16. Pause(p)

Step17. X = x+s*rand(n, 1)

Step18. Y= y+s*rand(n, 1)

Step19. End

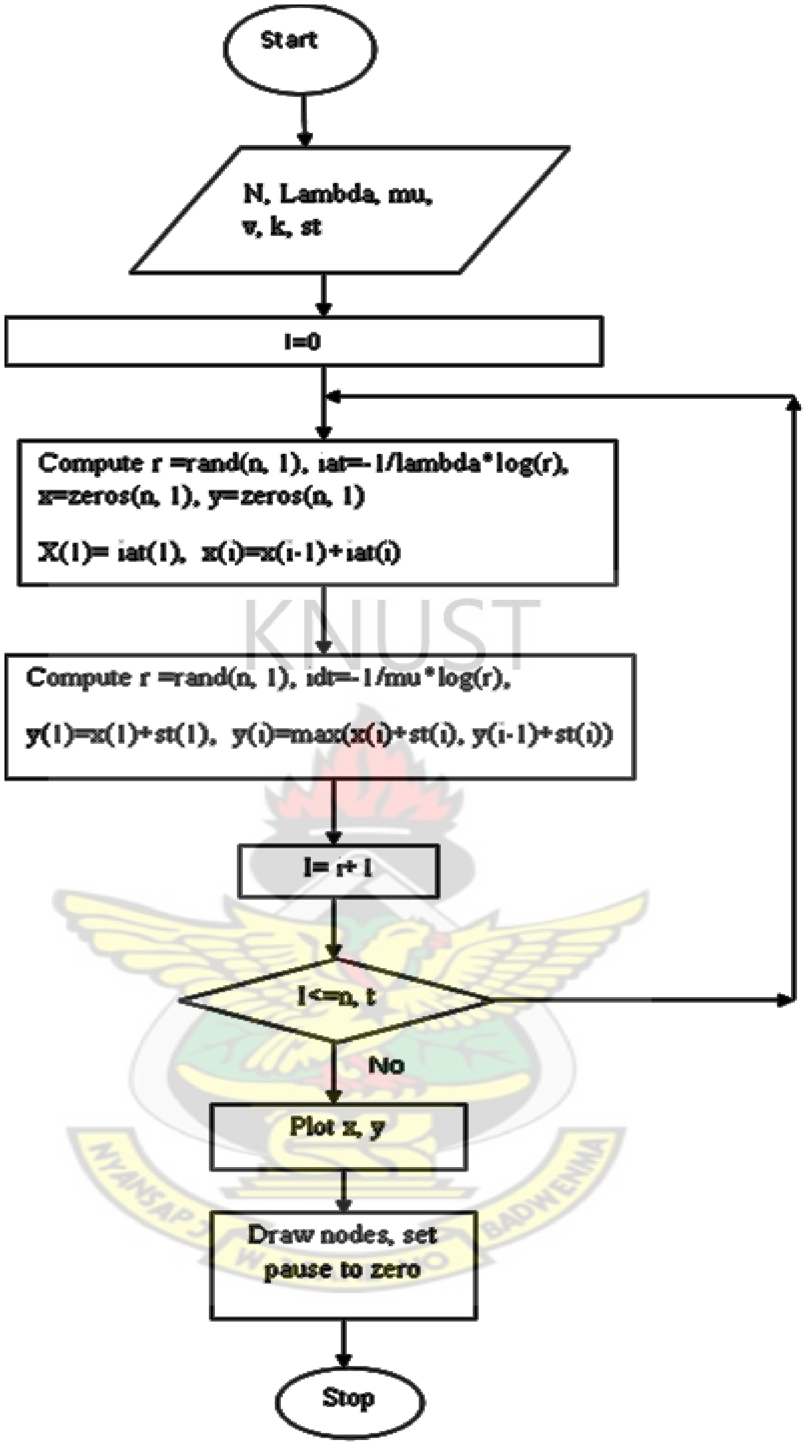


**Figure 3 2: Flowchart For Queueing Mobility Model**

Algorithm for Random Walk Model

Step1. Start

Step2. Input n, s, t, i

Step3. X = rand(n, 1)

Step4. Y = rand(n, 1)

Step5. H = plot(X, Y,'.')

Step6. Set axis

Step7. I=0

Step9. While I <t

Step10. Drawnow

Step11. Pause(p)

Step12. X = X+s*rand(n, 1)

Step13. Y= Y+s*rand(n, 1)

Step14. I =i+1

Step15. If I <=t Go to step10

Step16. End

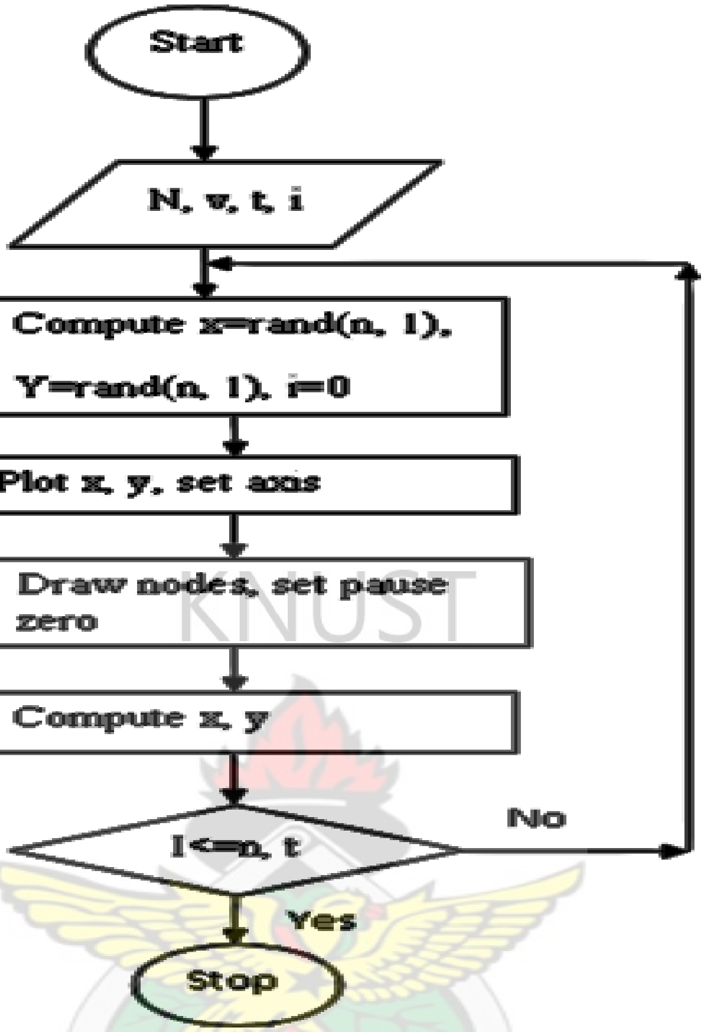


**Figure 3 3: Flowchart For Random Walk Mobility Model**

### 3.3.3. Simulation of Queuing Mobility Model

The flexibility of MANETs provides that each node can move arbitrarily but in reality, the nodes have a specific behavior which is dependent on the location and the intension of a node. Mobility is one of the main advantages of MANETs where the nodes can move arbitrarily with nearly no restriction. Such movements yield to different node distributions, arrival patterns and to different speeds.

### 3.3.4. Comparison Between Queueing Mobility and Random Walk Mobility Models

Simulation setup - Starting from an initial node distribution – which represents inhomogeneity, a mobility model was applied to all the nodes with a simulation steps. After the simulation steps elapses a snapshot of the node distribution was observed and analysed. The simulations were based on QMM to study the mobility of MNs from one area to another in a location. The simulations of the models were done using MatLab software. The user was allowed to input the number of nodes n, the number of mobility steps to perform for each simulation k and the speed of MNs s. Nodes were initiated from the origin of the simulation area. The simulation area was made up of square area of 300m X 300m. The table 3.2 shows details of the parameters used for the simulation of both QMM and random walk models.

**Table 3 2:Simulation Parameters**

| Parameters | Values |
|---|---|
| Simulation Area | 300m X 300m |
| Number of Nodes | 50, 100, 150, 200, 300 |
| Mobility Steps | 500, 1000, 10000, 20000, 30000, 40000, 50000 |
| Speeds | 0.1m/s to1m/s |

### 3.3.5 Poisson Arrival Distribution (Number of Nodes)

The arrival pattern of mobile nodes has an impact on the performance of the network. In this scope, we have decided to analysis the effect of arrival distribution on the MNs population in a given area by using Poisson distribution as in equation 2.1.

In most real-world MANETs, the node population in an area of interest varies with time. In this simulation, it is therefore necessary to investigate the impact of arrivals of MNs on the MANETs mobility.

The simulation area does not change as the arrival rate changes. The different values of arrival rates being considered in this study are shown in Table 3.3.

**Table 3 3: Varying Arrival Rates**

| Scenario | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Arrival rates | 0.3 | 0.4 | 0.5 | 0.8 | 0.9 |

During this simulation, nodes were allowed to enter the location from a common source (0 degrees) but not from different sources. The number of MNs that entered the location was assumed to be Poisson distributed with mean.



### 3.3.6. The Pareto Arrival Distribution

The arrival pattern of mobile nodes has an impact on the performance of the network. We assumed the arrival distribution on the MNs population by using Pareto distributions as in equations 2.6 and 2.8.

The Pareto distributions were characterized by two parameters: $\alpha$ and $\beta$. Parameter $\alpha$ is called shape parameter that determines heavy-tailed characteristics and $\beta$ =1 is called cutoff or the location parameter that determines the average of inter-arrival time.

**Table 3 4: Varying α parameter values**

| Scenario | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| α (B) | 0.3 | 0.4 | 0.5 | 0.8 | 0.9 |

For the simulations purposes, the varying α values was considered. Heavy-tail was modeled by a Pareto distribution and the main principle can be attributed to the principle of number of nodes. We have performed the simulations for a wide range of parameter values as in table 3.4 for both one-parameter and two-parameter Pareto models.

### 3.3.7 Impact of Varying Number of Nodes on Speeds

Various speeds against varying nodes densities were assumed. Speed has been set to 1m/s by truncating Gaussian (normal) mean of human walking speed of 1.34m/s. This has been accomplished by placing upper and lower bounds for the mobility rate and the speed used in the simulation range from 0.1m/s to 1m/s. with 0.1 step.

The number of nodes in the network was varied and their effect on speed were considered because network size in combination with simulation area provides a good measure of the density of network. The mobility algorithms' performance has been evaluated for cases where nodes'density is assumed to be dense or sparse. In this scenario, the number of nodes has been varied from 50 to 300.

## 3.4. Conclusion

In this chapter, the simulation methods employed, algorithms and flowcharts were presented. The next chapter illustrates the analysis of the simulation results such as the mobility of nodes using queueing mobility model, comparison of QMM against mobility models such as the random walk model, effects of arrival rates and variation of number of nodes on speeds.

# CHAPTER 4: ANALYSIS OF SIMULATION RESULTS

## 4.0. Introduction

In this chapter, we present simulation results of the Queueing Mobility Model and also compare the results of the mobile nodes arrival pattern as following Poisson and Pareto distributions. The impact of mobility on the network topology has also been carried out by varying each parameter that affects the mobility models of QMM and RWM.

## 4.1. The Mobility of Nodes Using Queueing Model

The general characteristics of the queueing mobility model and the effect of the arrival pattern of MNs following Poisson arrival in the simulation area is as shown in Figure 4.1. The observed patterns of MNs seem to move in queues and may be termed as platoon [18]. Platoons of nodes may arise where faster nodes are catching with slower nodes but not overpassing one another. Thus the nodes are in queues or lines behind each other, moving from one location to another location.

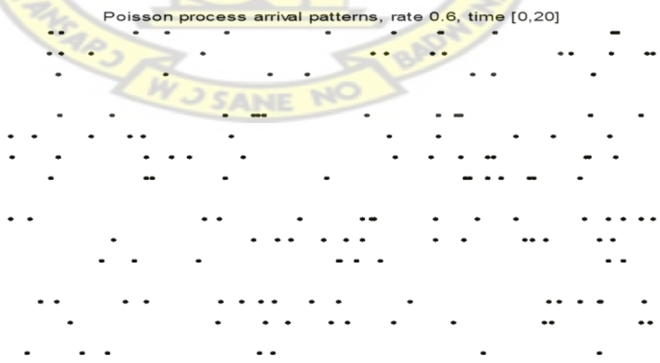


**Figure 4 1: Topology of Queueing Mobility Model**

## 4.2. Comparative Study of Mobility Models

For the comparative study, we have introduced the notion of a common source where MNs have a same entrance point. We also predefined the number of iterations for the simulation process of the nodes. We compared the QMM against mobility models such as random walk or Brownian mobility models. The program starts with user input window as shown in Figure 4.2.

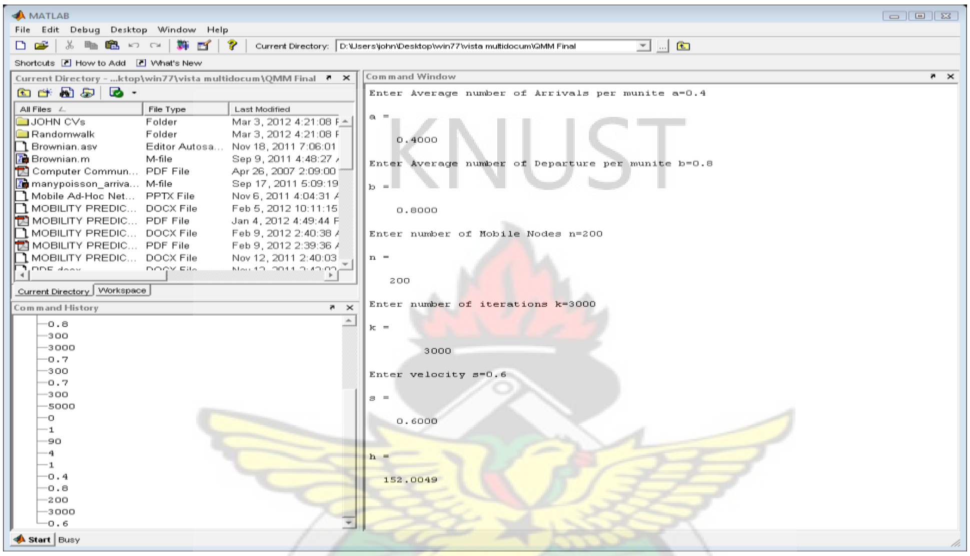


**Figure 4 2: Input command window in Matlab software**

The snapshot in Figure 4.3 was obtained after predefined simulation iteration.

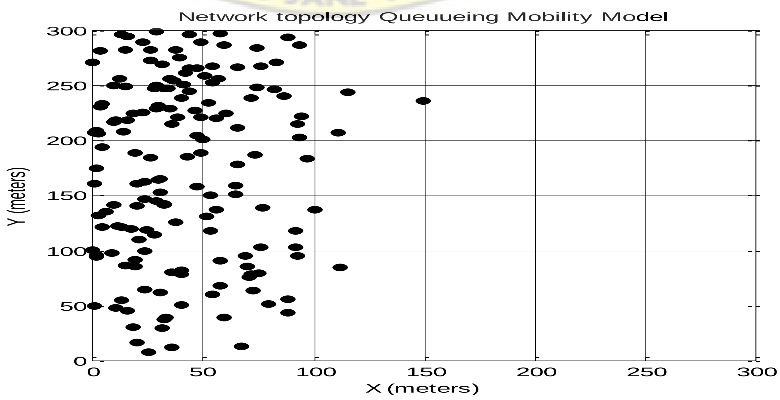


**Figure 4 3: Mobility using QMM with a predefined iteration**

The analysis in Figure 4.3 may indicate that if MNs have been forced to move in a certain order their trajectory therefore is similar to hunts movement. This shows out a typical human behavior when an area is being affected by a natural disaster or unexpected catastrophe. It may recall that a group of hunt always moves in group from a common source point; such a behavior is amendable for self-organized system as in Mobile Ad'hoc Networks. The radio nodes are assumed to be reconfigurable and acting as routers but having a coordinator point, as in MANETs mesh, or cluster topology.

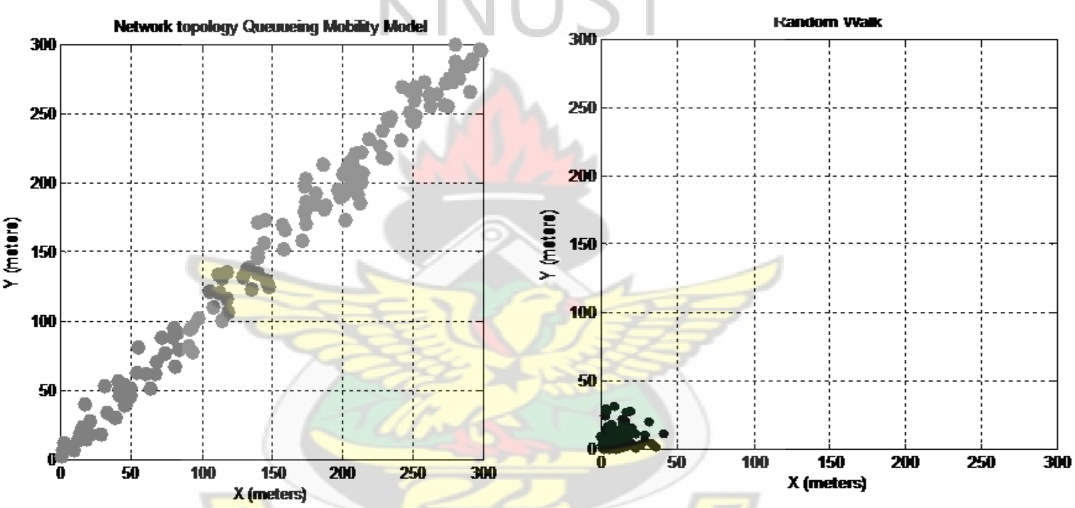


**Figure 4 4: Spatial nodes distribution at the 500th simulation steps**

In Figure 4.4, the simulation results on the usage of QMM with a chosen common starting point for MNs shows that the MNs span towards the ground in a given amount of time and take a smaller amount of time to cover an area completely, whereas the obtained results using random walk model with the same parameters such as speed, number of nodes, simulation steps and simulation area do not give the same pattern. This may be explained by the fact that the random walk model, may not give an effective transmission deployment of radio nodes when being used in a case of a natural misfortune alike an earthquake. The radio may not be able to forward the information since it shows a total stacking of radio nodes. Meanwhile for the Poisson model each radio point shows a forwarding movement then, any radio may be viewed as having adequate radius range of transmission. The information reliability is shown to be flexible in the mobility of mobile nodes, with a minimum colliding. It may show a proven for nodes deployment in wireless sensor networks for effective environment monitoring in remote areas.

One may note that the goal of mobility prediction in Ad'hoc network remains the mobility prediction model which best responds to self-reconfigurable radio systems. Consequently, the MNs coordination strategy is very delicate. The coordination point is assimilated to the common starting point, and a failing of node may have no impact on the network topology.

Emphasis is made on Figures 4.5 to 4.6 to illustrate the process of entry to a location from a source, forming line(s) and their departure into various areas within the location.

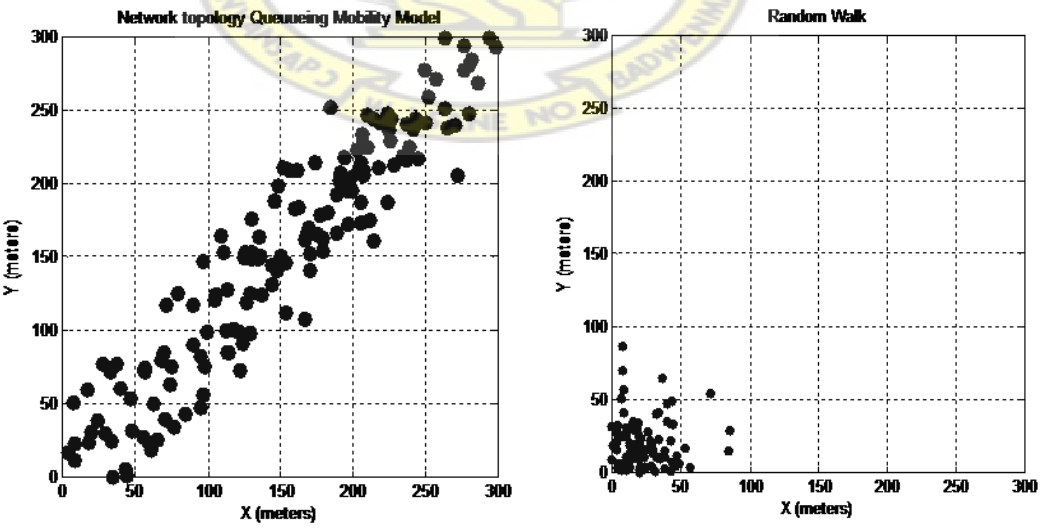


**Figure 4 5: Spatial nodes distribution at the 1000th simulation steps**

Each mobility model first places the mobile nodes in their initial locations and defines the way that the nodes move within the network.

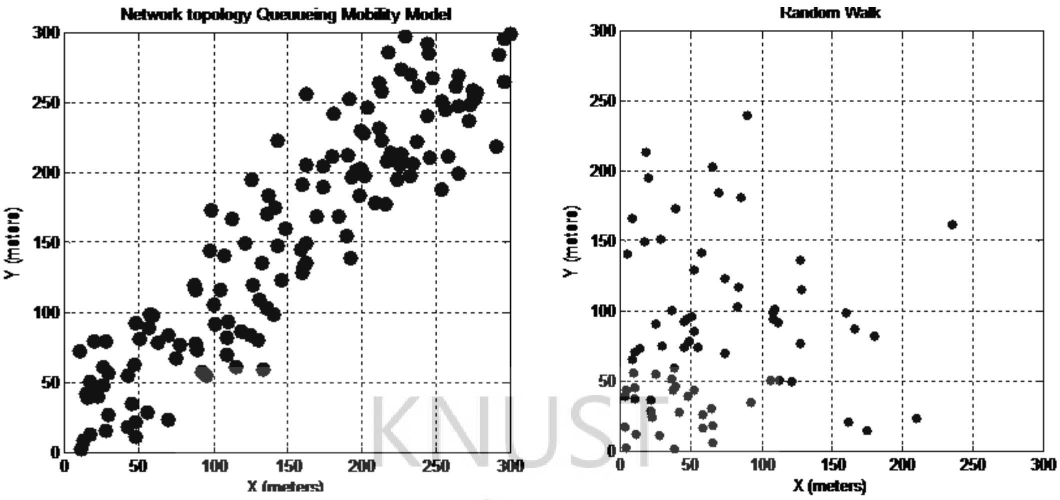


**Figure 4 6: Spatial nodes distribution at the 10000th simulation steps**

The QMM may show to have a smaller first entrance time than the random walk model and forms a line or queue from zero degrees to forty-five degrees direction and this leads to a uniform distribution of nodes in steady state. Once nodes have arrived in a location, the nodes will move around the location waiting for the arrival of others. Sometimes MNs arrive in a location waiting for their assign task while others are also joining them resulting to a queue. Hence, the influence of the mobility pattern and/or of the initial distribution on the spatial distribution after a large number of mobility steps on nodes distribution is also observed. The uniformity of the nodes' spatial distribution shows the dependency with the nodes speeds.

The observation in Figure 4.7 may illustrate that the QMM has "more uniform" nodes distribution compared to the random walk model as the number of simulation steps was higher between 40000 to 50000.

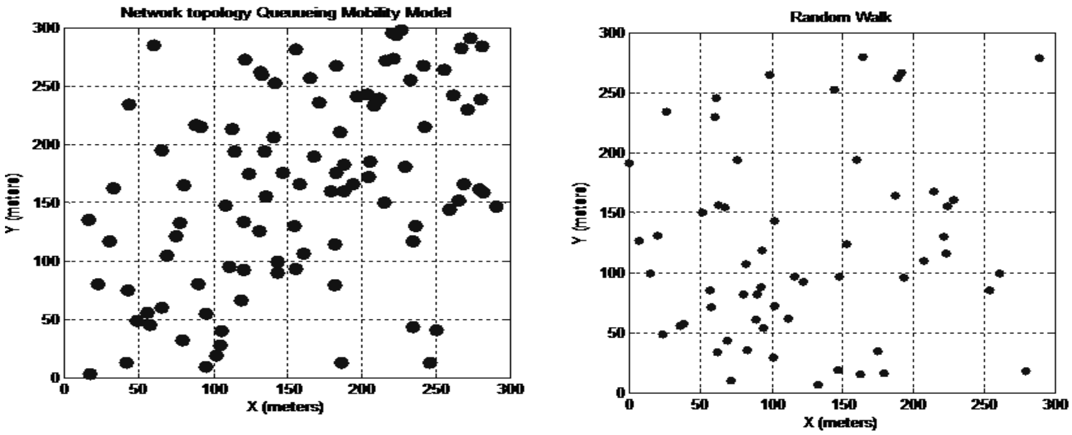


**Figure 4 7: Spatial nodes distribution at the 50000th simulation steps**

In real-world situations, MNs move to a particular destination for specific purposes. More number of nodes may move in groups towards areas of interest or service areas to receive services, sometimes wait or depart or exit immediately. MNs may also select the service areas to visit; there may be other nodes too which are also visiting the same service facility resulting in forming of queues/groups.

The above simulation plots from Figures 4.3 to 4.7 may indicate that MNs seemed moving in a line or queue, but as time goes on they were randomly distributed by forming different groups in queues with regard to Poisson model. The random walk may show a different type of group mobility which may refer to hunts movement when they meet an obstruction, a disturbance or a sudden sound they turn around in a scattered manner before proceeding. These may explain why MANETs with a random walk configuration do not find application in military battlefields. The point of entry which was at 0 degree but as they move away from the source to their destinations they begin to disperse just like the QMM. With the QMM nodes are distributed evenly in the simulation area in the long run unlike the random walks which has more nodes at the location closer to the source. The QMM provides solution to the random walk model, in which MNs reaches the simulation area, wraps to the opposite edge and continues with its movement.

MNS at the front of the queue depart or exit the simulation area as early as possible compared to those at the tail of the queue at the beginning. Some of MNs may return whilst others may move away from the initial group and queue forming subgroups. For a vast simulation period MNs in the group initially dispersed into separate groupings with some of them even moving independently. In the Random Walk model, the mobile nodes were considered moving independently from one another. This kind of mobility model is classified as entity mobility model [1, 2] and however in some scenarios including battlefield communication and museum touring, rescue missions etc., the movement pattern of a mobile node may be influenced by other nodes in the neighborhood.

## 4.3 Effect of Varying Arrival Rates

In Figure 4.8, the effect of varying nodes' arrival rate is computed using Poisson model. Nodes may arrive at a location either in some regular pattern or in a totally random fashion. The arrival rates have shown to impact on the number of nodes in a particular location, although every location has a limited capacity. A high number of nodes typically translate into a higher average number of neighbours per node, which influences the route availability. The physical implication of mobility in node encounters has been ignored in the past.

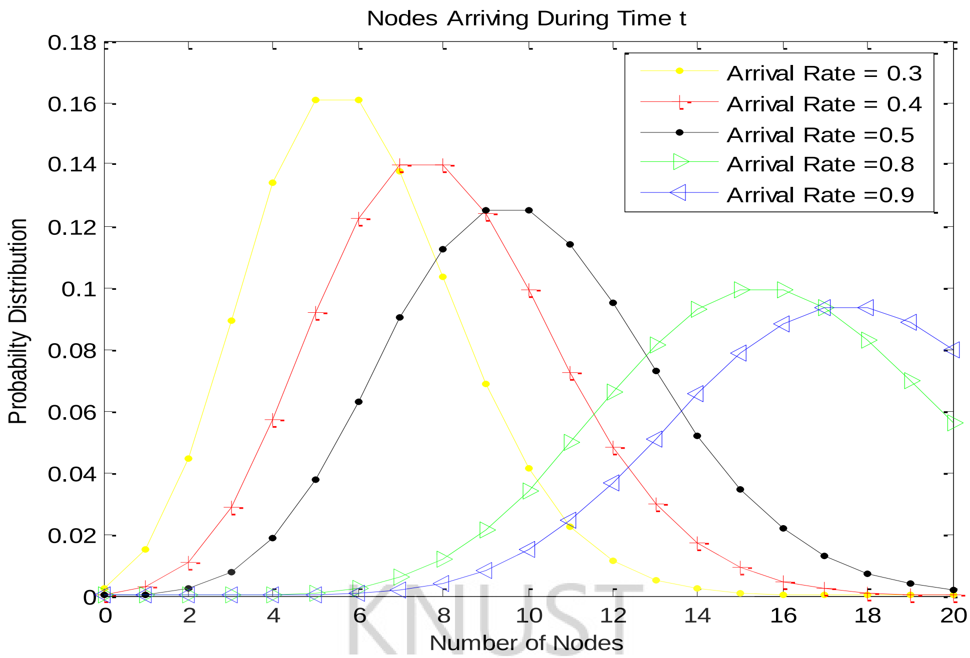


**Figure 4 8: For Twenty Number of Nodes for varying Arrival rates**

In reality, the total connection time of a node over a specific interval depends on the nodes encounter rate and the time in each encounter, both of which depend on the relative mobility of nodes.

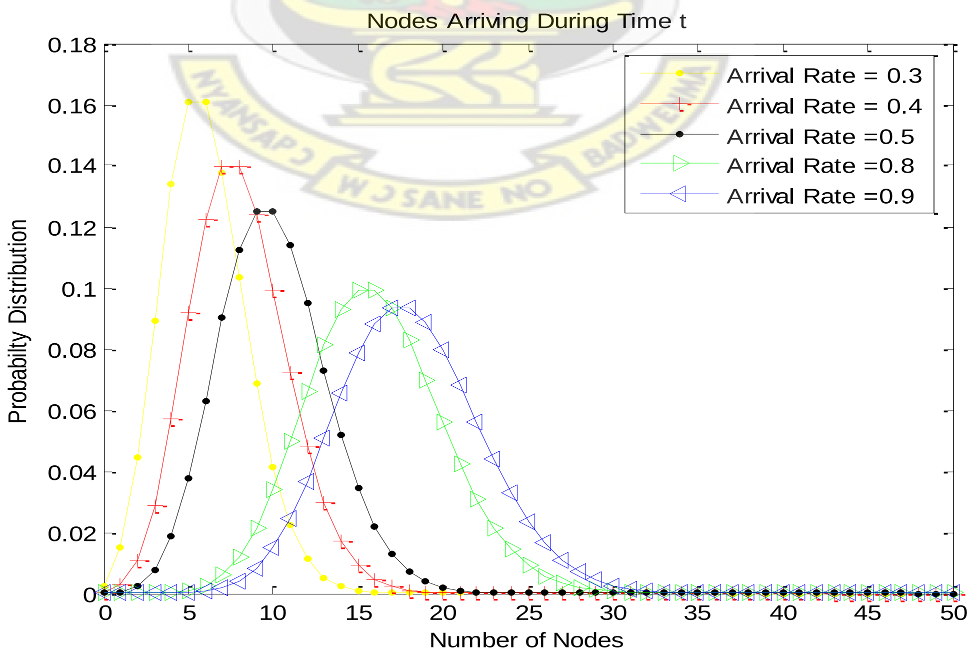


**Figure 4 9: For Fifty Number of Nodes for varying Arrival rates**

Although a high node arrivals results in more node encounters, the network would eventually become congested. The impact of this relationship is that nodes can and will be tightly packed (ie. High density) if their arrival rates is high (congestion), but if the arrivals is lower, the nodes may be farther apart (low density). For instance it is clear that there is some congestion for arrivals of MNs, since they have to follow some holding paths.

As the value of arrival rate increases, the shape of the distribution changes dramatically to a more symmetrical (”normal") form and the probability of a larger number of arrivals increases with increasing number of MNs. An interesting observation is that as the arrival rate increases, the properties of the Poisson distribution approach those of the normal distribution as in Figures 4.8 and 4.9.

From Figures 4.8 and 4.9 nodes with higher rates of 0.5 to 0.9 have mean number of nodes as 10, 15 and 18 with probabilities of arrivals as 0.1251, 0.9922 and 0.0936 respectively. The variation in the nodes arrivals at the various locations can cause the number of nodes arriving to vary substantially. The probability for other number of MNs arrivals can also be computed.

The first arrival processes of nodes give higher contact probabilities at higher arriving rates. This is due to the nodes’ contiguity one to another making mobility difficult. In practice, one may record the actual number of arrivals over a period and then compare the frequency of distribution of the observed number of arrival to the Poisson distribution to investigate its approximation of the arrival distribution.

Table 4.1 was obtained from Figure 4.9 by extracting the maximum PDF values and their corresponding number of nodes and the arrival rates.

**Table 4 1: Number of Nodes, Maximum PDF and Arrival Rates**

| MN | Ymax | Arrival Rates- r |
|---|---|---|
| 5 | 0.1606 | 0.3 |
| 8 | 0.1396 | 0.4 |
| 10 | 0.1251 | 0.5 |
| 15 | 0.9922 | 0.8 |
| 18 | 0.0936 | 0.9 |

The Poisson arrival distribution is not a very good approach for different variances of the number of nodes in an area as it is simpler but less realistic.

## 4.4. Comparative Study using Pareto Arrival Pattern

In this section, the effect of arrival rates on MNs distribution and population in a defined location was analyzed as shown in Figure 4.10.

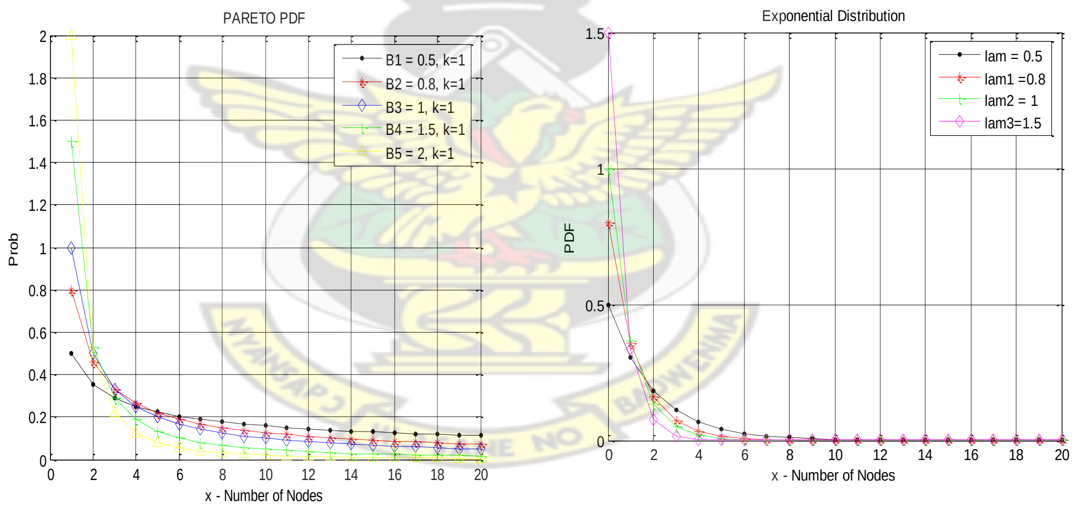


**Figure 4 10: Single Parameter for Varying Values for B, and Exponential for Twenty Nodes**

It was observed that the various arrival rates increased, the number of MNs also increased but to a certain limit. It is therefore the indication that every location has a limit or capacity of MNs it can contain. The Poisson arrival is not good for modeling the arrival of the MNs, therefore the use of heavy tailed distributions such as the Pareto distribution. We therefore decided to use the Pareto distribution since it has nice properties that make it very tractable. Though not very realistic from a practical point of view, a model based on the exponential distribution can be of great importance to provide an insight into the arrival pattern.

In real-world the node arrival contains a heavy-tail but not the Poisson distribution. The MNs arrival pattern of the Pareto distribution are independent and identically distributed, which means that each arrival has the same probability distribution as the other arrival and all are mutually independent.

Figures 4.10 and 4.11 may indicate that the exponential distribution was higher than the single parameter in the initial stages but as time progresses the exponential decreases fast to zero. The single parameter Pareto overtakes the exponential as the number of nodes increases and indication that the single parameter performs better than exponential distribution.

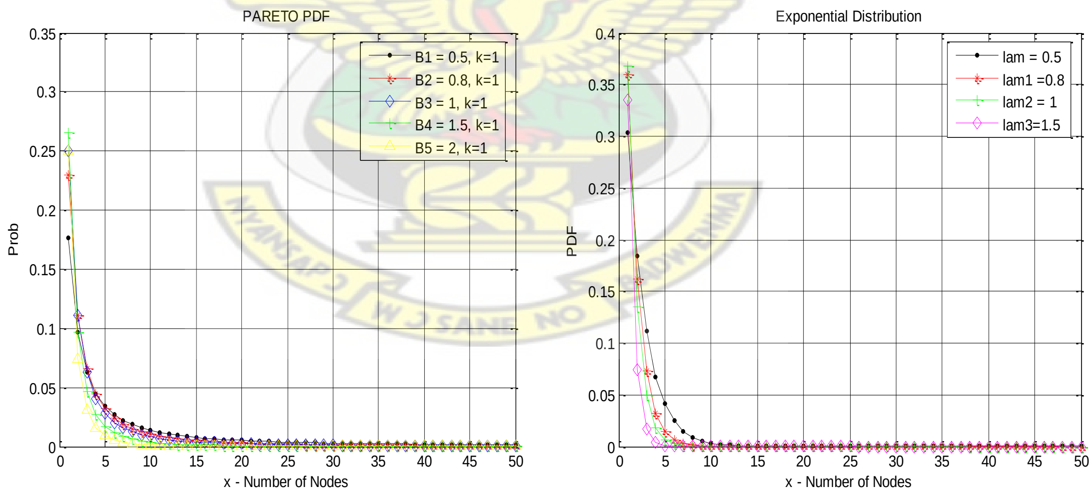


**Figure 4 11: Single Parameter for Varying Values for (α )B, with Exponential for Fifty Nodes**

Figure 4.11 shows a comparison between Pareto and Exponential probability density distributions with varying arrival rates. The Pareto distribution has tail that decays much more slowly than the exponential distribution. The alpha is the shape parameter which determines the characteristics "decay" of the distribution (tail index) and A is the location parameter which defines the minimum value of x (number of nodes).

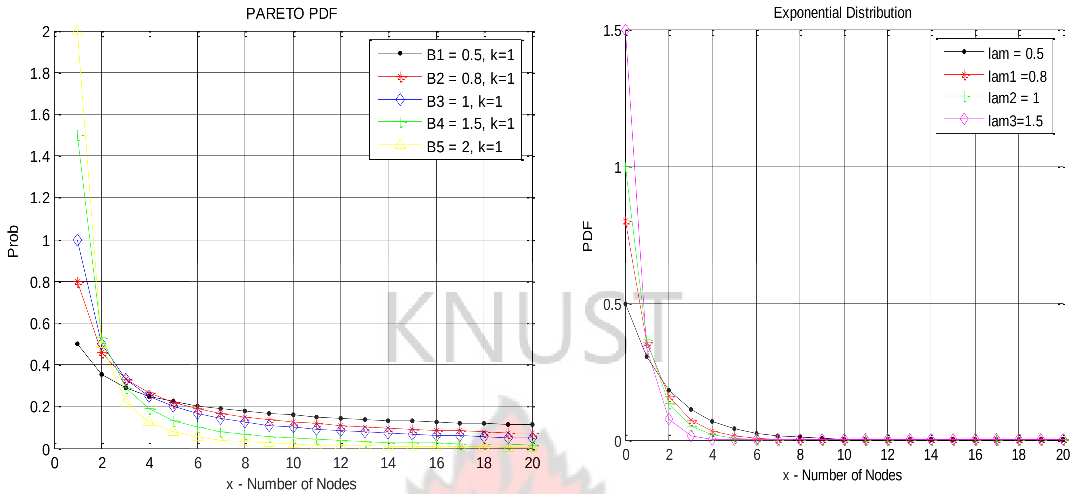


**Figure 4 12: Two Parameter Pareto for Varying B Values and Exponential**

In Figures 4.12 and 4.13, the comparison between the two-parameter Pareto and exponential distributions is illustrated. It is obvious that the two-parameter Pareto outweighs the exponential distribution as the number of MNs increases. The exponential distributions decays very fast and finally get to the a-axis unlike the two-parameter Pareto distribution where some of the arrival rates distribution has not decay to zero.

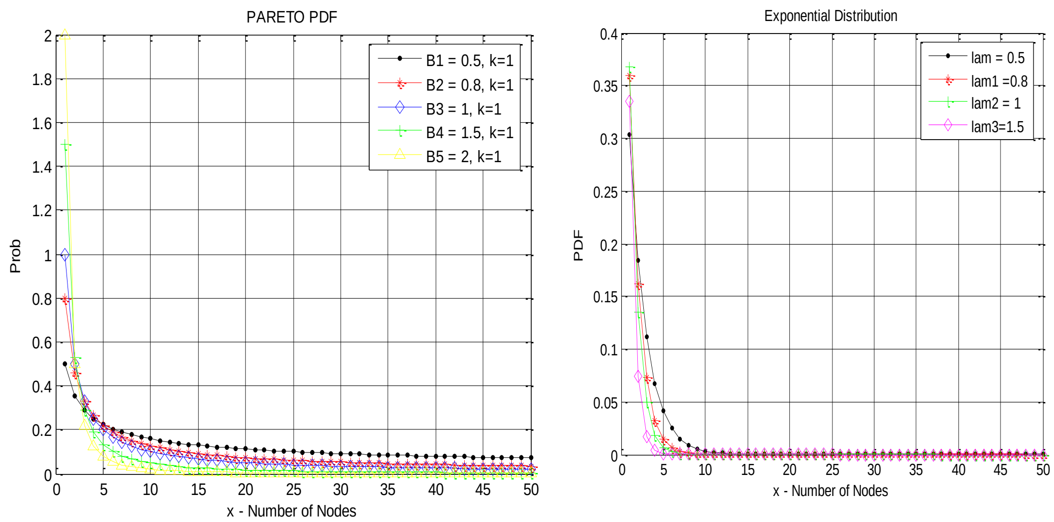


**Figure 4 13: Two Parameter with Fifty Nodes**

However the two-parameter Pareto performed well than the one-parameter Pareto, since some of the arrival of the two-parameter did not decay to zero. The long-tailed nature of the two-parameter Pareto helped to clear out any congestion in a location when the arrival rate was small and the reverse was also true. The Pareto arrival distribution is therefore a very good measure for different variances of the number of nodes in an area.

## 4.5. Effect of Varying Number of Nodes on Speeds

The Figure 4.14 shows the results of speeds ratios varying density of nodes within the network area using Poisson model.

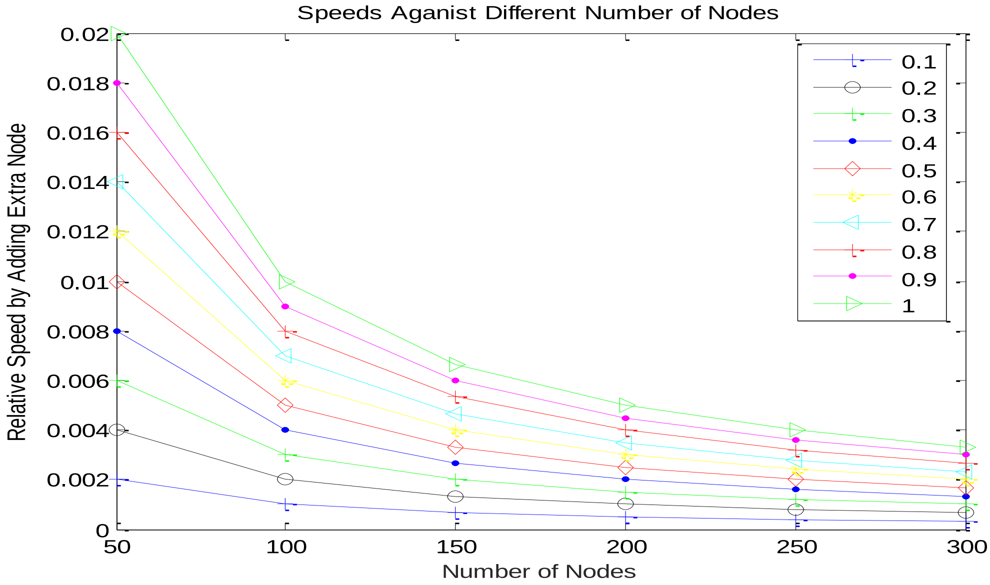


**Figure 4 14: Variation of MNs on Different Speeds**



The observation analysis may indicate that speeds ratio decreases with increases in the number of MNs within the network. The physical implication of mobility rate in node encounters has been glossed over. In reality, the total connection time of a node over a specific interval depends on the nodes encounter rate and the time in each encounter, both of which depend on the relative mobility of nodes. Although a high node speed results in more node encounters, the connection time in each node encounter also decreases. When a node with a higher desired speed catches up with a slower moving node, it will either follow or overtake (bypass) [18]. The impact of this relationship is that nodes can and will be tightly packed resulting to High density, if their speed is low resulting to congestion, but if the speed is higher, the nodes would be farther apart resulting to low density. In Figure 4.14 illustrates that one need not have many nodes before a slow node becomes a bottleneck.

In Figure 4.14 it can be observed that as the number of the nodes increases, the speed of the nodes decreases. This is because nodes are closed to each other making mobility difficult. One may say that the network under study is crowded with nodes.

As the number of nodes increases it could be better to increase the speed of the nodes, so that the nodes can move faster to give room to other nodes. In all, if the number of nodes is higher then speed must be increased for better mobility which is the opposite in the case of fewer nodes. It also means that nodes have a number of hops to get to their destination nodes. The larger the number of nodes means it require higher speed in order to get to a particular location. A decreased in the number of nodes in an area implies a decreased in the connectivity of nodes i.e., each node has fewer neighbours. A decreased in connectivity also implies lesser information exchange hence less input to the algorithm. An increased in the number of nodes implies high connectivity among nodes; more information is exchanged and hence more input to the algorithm. It is therefore important to conclude that when the nodes are many in a particular location, it would be wise to increase the speed to a certain limit. It could be observed that in all cases of speed against increased in nodes there was a decreased in speed. The distributions of speeds for the nodes have an impact on their connectivity and mobility. However, a large span of speeds also results in a wide range of connectivity.



## 4.6 K-Factor for Distance Correlation on Mobile Node Speed

In order to determine the k factor as given in equation 2.11 and given as equation 4.1:

$$Cor_{dist} = k * \sum \frac{\|d(t),\ d(t+\Delta t)\|}{\|d\|} \qquad 4.1$$

We have applied Kolmogorov-Smirnov (KS) test [31] to the obtained results in Figure 4.14 which yields the Table 4.2. In Figure 4.15, the plot of the $k$-factor against the number of mobile nodes was shown.

$$k = |\text{ymax} - \text{ymin}| \qquad 4.2$$

**Table 4 2: Relative Difference between Maximum and Minimum Speeds Against Number of Nodes.**

| MN | Ymin | Ymax | $k$ |
|---|---|---|---|
| 50 | 0.002 | 0.02 | 0.018 |
| 100 | 0.001 | 0.01 | 0.009 |
| 150 | 0.00067 | 0.0067 | 0.00603 |
| 200 | 0.0005 | 0.005 | 0.0045 |
| 250 | 0.0004 | 0.004 | 0.0036 |
| 300 | 0.00033 | 0.0033 | 0.00297 |

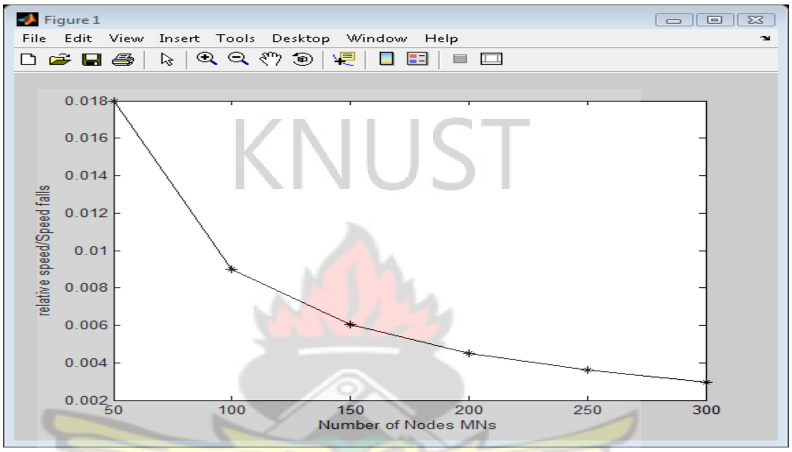


**Figure 4 15: Relative fall as the number of nodes increased**

It may also be observed that the relationship between the k values and the number of nodes is an exponential function with a negative decay. Therefore the distance correlation as in Equation 2.11 may be approximated to one Pareto shape factor function with Mean denoted as $\alpha_1 = 0.735$ which is the mean value of k. It comes that:

$$f(x) = \left(\frac{0.735}{1+X}\right)^{0.735}$$

With regard to $\alpha_2 = 0.527$ as the median value of k, we can write

$$f(x) = \left(\frac{0.527}{1+X}\right)^{0.527}.$$

A comparative study is made in Figure 4.16 which depicts the use of the mean and median as one shape factor. Obviously, both quantities give the same layout meanwhile one may argue that the use of the median gives a better approximation as obtained in the Figure 4.16. Thus it may indicate that the distance correlation may be achieved if one considers the median value of the distance correlation parameter for a better approximation in mobility prediction for geocasting network [32] and may certainly be helpful for location awareness system as needed to characterise human mobility [33-34].

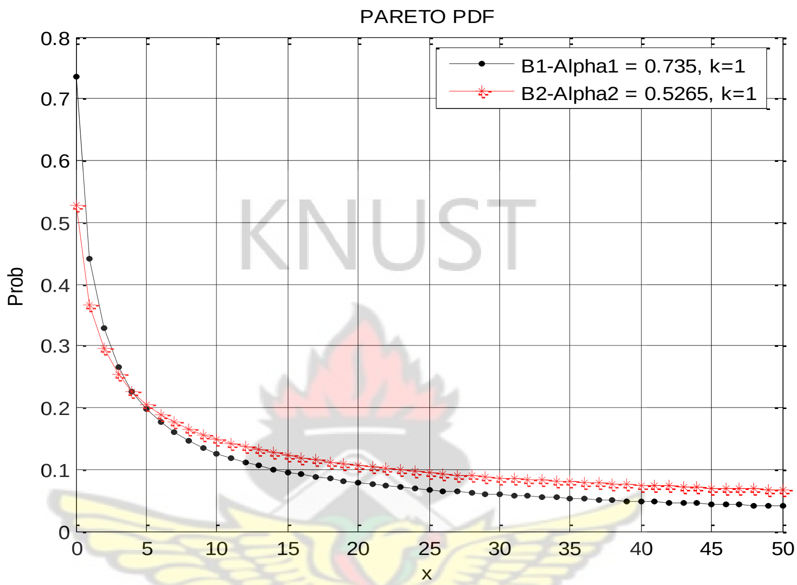


**Figure 4 16: Single Parameter Pareto Distribution with Fifty Nodes**

Over the years, it turns out that the speed ratio node density was always a weak point in design of mobility model. But now we can find that the distribution of speeds over the number of nodes fits heavy-tail/Pareto distribution according to our result. The distribution of speeds ratio number of nodes has been proved to be realistic, since the relation we used to connect speeds and number of nodes is also realistic [35].

## 4.7 Conclusion

This chapter has discussed the analysis of simulation results such as Poisson arrival of MNs as well as Pareto arrival distribution and their impact on nodes population in an area. We also considered the relationship between different speeds and the number of nodes in the simulation area – a difference between the long-term distribution of nodes and the initial distribution. A comparison of the QMM with RWM in terms of non-homogeneous point of entry was also considered. The results indicated that the QMM in-cooperate both the regular and random mobility model as well as the group and entity mobility models, as initially the nodes were together but dispersed into different areas as time progresses.

# CHAPTER 5: CONCLUSION AND FUTURE WORKS

The field of mobile ad hoc networks has received significant attention during the last decade due to mobility of MNs. Among the risk factors, mobility is one of the most fundamental and challenging in MANETs. Therefore, it is not an overstatement that the study of mobility models has important implications from the MANETs point of view. Our simulation studies modeled a network of mobile nodes placed non-homogeneous at the entry point for simulation area of 300x300 meter. Each simulation was run for a number of simulation steps.



The input parameters involved in this study were speeds, number of nodes, simulation steps and arrival rates. The nodes were entry from a common source for both QMM and modified RWM.

The nodes may take time to heat up, in view of that at the beginning all the nodes were in a queue for the QMM whiles they have been together as a group in the random walk model. As time goes on, the nodes have been dispersed from the queue or line into sub-groups but then some still remain in the queue while others were independent, moving from one area to another area within the simulation area. The Queueing Mobility Model for MANETs may behave like the random mobility model since the simulation area may be unbounded. It means that some of the nodes finally leave the location or simulation area never to return whiles others returned. Some of the MNs may continue to follow the same direction whilst others move in different directions just like Random walk mobility models. It may be seen as soldiers in a queue marching together, each soldier stands next to his/her counterpart while marching/moving in uniform manner. In Queueing Mobility Model, nodes may be in line(s) moving from one place to another within the location. Therefore queueing mobility theory is very important for modeling mobility of nodes. If the number of nodes increases, the number of flows in the line or queue also increases.

The initial MN position may not be uniform (non-homogeneous) at source, however, with time, the distribution of MN positions tend to be homogeneous in the simulation area for QMM. Also with the RWM the distribution of the MN position may be non-homogeneous, that is the trend turn to be dense toward the source and the middle of the simulation area.

We have shown the effect of arrival rates on MNs distribution and population in a location. It may claim that as the various arrival rates increased the mean number of MNs may also increased but to a certain limit. It is therefore the indication that every location has a limited capacity. The various arrival rates may also increase the MNs population to some point and then reduced to zero.

The arrival patterns have shown some impact on the network population, as the arrival rate increases the MNs population also increases to a peak and then decays rapidly to the x-axis. It was realized that the Poisson distribution is not good for the arrival distribution; therefore the Pareto distribution was considered. It has come out clear that the Pareto distribution is good for the arrival distribution, especially the two-parameter Pareto distribution which performed better than the single Pareto and exponential distributions even though at the earlier stages the exponential performed well than the single Pareto distribution with a faster decay. The Pareto distribution is more reflective of the modeling mobility for MANETs than the Poisson distribution.

We have also considered different speeds distributions against the number of MNs and it was observed that as the number of MNs increased the speed also falls very fast and there has been a need to increase the speeds; so that MNs may move faster to give room to other nodes.

It may subsequently be admitted that mobility in MANETs is a difficult work and actually, it is an interesting research area that has been growing in recent years. Its difficulty is mainly generated because of the continuous changes in the network topology with time. The topological changes have impact on mobility techniques developed for infrastructure-based networks thus may not be directly applied to mobile adhoc networks. We have investigated through simulation mobility prediction of MNs using the queueing model. The queueing model provides detailed analysis of the Poisson arrival process and MNs topology. The simulation results have also indicated the effects of the arrivals, node density on speeds and comparison of QMM with known mobility models such as random walk/Brownian.

Furthermore, the simulation results based on number of nodes to speeds relationship indicated that a better mobility can be achieved with higher speed as the number of nodes increased and performed better with a small number of nodes move with lower speed.

Our future work will investigate MNs mobility and its effects on human mobility. End to end delay on routing protocol algorithm in location awareness network. It may be necessary to implement it, by using traces in order to validate the QMM and its reality.

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