AD HOC WIRELESS ROUTING WITH DENSITY BASED PROBABILISTIC ALGORITHM FOR MOBILE WIRELESS NETWORKS WITH NON-UNIFORM NODE DISTRIBUTION

by

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The journey in completing my Master's thesis in USM was an enlightening one. I will always be pivotal important moment in my life. Many lessons were learned from the mistakes I made. I can never thank you enough for the people who have been part of my journey.

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LIST OF TERMS AND ABBREVIATIONS

AODV	Ad Hoc On Demand Distance Vector
DENSE	Density definition for $P(1\text{-}con) \geq 0.95$
DSR	Dynamic Source Routing
HD	High Density
MANET	Mobile Ad Hoc Networks
MPR	Multi Point Relay
OLSR	Optimized Link State Routing
QoS	Quality of Service
RREP	Route Reply
RREQ	Route Request
SD	Sparse Density
SPARSE	Density definition for $P(1\text{-}con) < 0.95$
VD	Varying Density

Penghalaan Tanpa Wayar Ad Hoc dengan Algoritma Kebarangkalian yang berasaskan Kepadatan untuk Rangkaian Tanpa Wayar Mudah Alih yang Mempunyai Pembahagian Nod yang Tidak Seragam.

ABSTRAK

Rangkaian tanpa wayar mudah alih boleh berfungsi walaupun terdapat rangkaian infrastuktur yang terhad ataupun langsung tiada rangkaian. Tambahan pula, rangkaian tanpa wayar mudah alih ini bersifat dinamik dan senang berubah yang memang berbeza dengan rangkaian tanpa wayar yang wujud sekarang. Sebab rangkaian tanpa wayar yang wujud sekarang ini hanya boleh menanggung komunikasi yang satu jarak lonjatan dari infrastruktur. Kajian yang dibentangkan ini mempertimbangkan isu penghalaan tanpa wayar ad hoc mudah ailh yang mempunyai lonjatan berganda di kawasan besar dengan ketumpatan nod yang berbeza-beza.

Lokasi yang dikemukan dalam kajian ini mempunyai persamaan dengan kawasan yang dilanda bencana alam ataupun kawasan pedalaman. Walaupun nod mudah tanpa wayar dalam tempat kajian ini tidak bertaburan dengan seragam tetapi nod ini akan bertabur dengan lebih banyak pada kawasan yang mempunyai orang ramai. Sebaliknya lebuhraya dan jalan mempunyai ketaburan nod yang rendah.

Kajian ini mengemukakan tiga jenis corak gerakan nod-nod rangkaian tanpa wayar mudah alih yang merupai situasi di persekitaran bandar, lebuhraya atau bencana alam.

Senario corak pergerakan kajian ini dibahagi kepada tiga topologi iaitu HD, VD dan SD. Penyebaran nod dalam topologi HD lebih padat dan saiz kawasan topologi ini adalah kecil. Topologi VD mempunyai kepadatan nod yang berbeza-beza dan saiz kawasannya adalah sederhana berbanding topologi lain. Topologi SD mempunyai saiz kawasan yang terbesar dan nod dalam topologi ini tersebar luas dalam topologi ini.

Kajian awal yang dikemukakan, berbincang tentang protokol penghalaan tanpa wayar mudah alih AODV (Ad Hoc On demand Distantance Vector) dan OLSR (Optimized Link State Routing). Kedua-dua protokol yang dicadangkan pernah dijalankan kajian dalam saiz rangkaian tanpa wayar dalam kawasan yang lebih kecil untuk membandingkan prestasinya. Sumbangan utama yang dibentang dalam kajian ini adalah pengunaan algoritma kebarangkalian yang berasaskan kepadatan nod dalam protokol penghalaan rangkaian tanpa wayar mudah alih. Algoritma yang dicadangkan akan digabung dengan protokol AODV untuk mengurangkan keborosan penghalaan yang berlaku dengan protokol AODV yang kian ada. Protokol AODV-P yang mengunakan algoritma kebarangkalian dibandingkan dengan protokol AODV-UU dan OLSR-UM yang merupakan protokol yang telah dilaksanakan dlam pelbagai kajian.

Kajian ini menunjukan AODV-P mempunyai peningkatan prestasi dari segi truput dengan purata sebanyak 10% berbanding AODV-UU dalam ketumpatan nod yang berbeza-beza. Kecekapan AODV-P dalam mengunakan 60% daripada purata jalur lebar yang disumbang ke dalam rangkaian berbanding dengan AODV-UU. Nilai-nilai dari sukatan lain juga menunjukan AODV-P mempunyai prestasi yang lebih baik berbanding AODV-UU terutamanya sukatan masa hayat pautan. Sukatan masa hayat pautan menunjukan

Ad hoc Wireless Routing with Density Based Probabilistic Algorithm for Mobile Wireless Networks with Non-Uniform Node Distribution.

ABSTRACT

Ad hoc wireless networks can operate even when there is limited or no network infrastructure. It is the dynamic and volatile nature of these networks that sets it apart from existing wireless networks. Current wireless networks could only support communications one hop away from the infrastructure range. The research presented in this thesis examines large multiple-hop ad hoc wireless networks that have varying node densities. Such environments can be can be found in areas struck by disasters to urban city environments. Mobile nodes would not distribute evenly in such environments but would likely concentrate around specific landmarks or areas such as public squares with a high number of pedestrians, while connecting roads and highways have low density of mobile nodes

This thesis introduced three custom mobility scenarios based on the different density configurations that mimic urban areas, highways or disaster area. The mobility scenarios were separated into three topologies HD, VD and SD. The node distribution in the HD topology were concentrated a smaller area. The VD topology has a mixture of different node distribution across a medium sized area. The node distribution in SD topology were scattered across a large area.

The main contribution in this thesis was the integration of a density based probabilistic scheme on AODV to reduce incurred routing overheads and improve packet delivery without impacting significantly the throughput and end to end delays. The proposed AODV-P (Ad Hoc On Demand Distance Vector – Probabilistic) protocol was compared against the AODV-UU and OLSR-UM (Optimized Link State Routing) protocol via simulation using NS-2 The evaluation was based on 3 different environments namely HD, VD, SD for several parameters such as delivery ratio, throughput, normalized routing overheads, average delays and link lifetime.

The study showed that in varying density environments, the AODV-P has higher data throughput than AODV-UU in low to medium speeds by 10%. The reduction of routing overheads for AODV-P is around 60% compared to AODV-UU for varying density environments. Other parameters for AODV-P also show the performance was fairly close in terms of average delay (less than 1 second) and average hop counts (around 1 hop). The link lifetime metric showed AODV-P was able to sustain links better than AODV-UU by an average of 15 seconds. The overall results showed that AODV-P performed better than AODV-UU and OLSR in sub-optimal network environments due to the improved link lifetimes and lower routing overheads.

Therefore a more ubiquitous approach to wireless networking is to be desired, especially during times when there is a scarcity of infrastructural support. One of the earliest forms of such ubiquitous networks tested by DARPA was the "packet radio network". This form of network then began to evolve into what we know today as the wireless ad hoc networks. The wireless ad hoc networks was built on the same layer two frame of 802.11 but its very different in terms of routing and network administration. More significantly is the reduced amount of infrastructure needed to run a local area network and gives it the advantage in terms of mobility and availability. Ad Hoc Networks could also communicate over multiple hops based on the routing protocols used. The current wireless ad hoc networks are categorized into different setups which includes Wireless Mesh Networks, Wireless Sensor Networks and Mobile Ad hoc Networks. These networks are different in terms of usage purposes, protocols and functionalities.

1.2 Motivation

Mobile Ad hoc Networks in particular could prove to be more useful in the future where mobile networks are getting more demanding in terms of its usage. If we can just project a decade into the future we would find that current infrastructure networks would only find its place in core service networks and large network backbones. Network applications today are facing one of the toughest challenges in its use which is mobility. One could imagine that one day we can scale up a local ad hoc wireless network and simultaneously connect to an AP much further than the permitted range. Such feat could only be achieved if there are multi-hop mobile networks available. Wireless access could then be extended to a larger scale limited only by the network latency and not the limited by the range of the wireless transmission, which is approximately a few hundred meters (MANET, 1999). There are many problems and issues that need to be addressed for a MANET protocol to be implemented for mobile applications and devices.

One of the main issues or problems that needed to be addressed for MANET is the movement and the dynamic change that occurs in the connectivity over a certain period of time. Depending on the available device, there is a diverse range of network setups when considering devices with high mobility. Again, applications within these devices must be robust enough to handle such situations when they occur. There is no guarantee that a mobile device would remain in its position over long periods of time.

Deploying MANET in real life scenarios with a mixture of vehicular and pedestrian traffic or disaster areas would have node distributions that lack uniformity. A non-uniform distribution of nodes imposes a problem for MANET as the nodes are required to be near one another to communicate. Such a scenario was discussed in (Heimlicher et al, 2009) when determining scenarios for its studies on partially connected networks. The uneven distribution of nodes in an area was identified to be a contributive factor for poor or limited connectivity for a multi-hop wireless network such as MANET.

An example of a non-uniform node distribution in a network can be seen in Figure 1.1. Figure 1.1 shows a real life example a non-uniform node distribution in an urban area. Usually the node distribution in buildings is higher than open areas, thus in Figure 1.1 it is assumed that BUILDING A, B, C and D has a very high node distribution in its vicinity. The moving cars (vehicular traffic) and mobile devices (pedestrian traffic) are assumed to have lower node density. The communication between the nodes in the buildings and the mobile devices or cars in Figure 1.1 is identified to have a network with lower connectivity in (Heimlicher et al, 2009). In such conditions MANET nodes are more susceptible to link breakages and will perform redundant broadcasts for route solicitation.

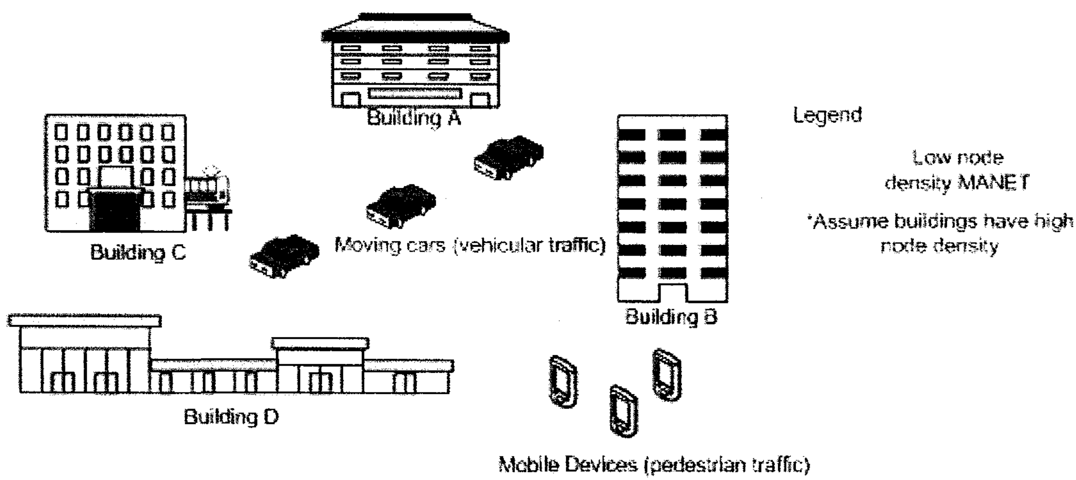

Figure 1.1 Example of non-uniform node distribution in real life scenarios

Frequent solicitation of routing information via broadcast performed by MANET nodes in densely populated areas exposes the network to a problem known as "broadcast storm". This event occurs when a high number of broadcast activities are performed simultaneously at a certain point of time and triggering torrents of redundant broadcasts requests and replies that will eventually lead the contention based link layer of MANETs to suffer a blackout (Ni et al. 1999). In networks with varying node densities, such problems is expected to occur more frequently as MANET nodes will be forced to retransmit its broadcasts whenever there is a broken link or when the destination could not be found after a certain period of time. The performance of the communications link in the network will eventually decline due to such aggressive broadcast activities.

In short, the problems found in MANET networks with varying node distributions are:

experimentation and research in this thesis was conducted based on the following assumptions:

- The physical layer used in the simulations will be based on a free space model where there will be no obstacles or terrain effects
- The transmission ranges used will me identical for all nodes
- The mobility for different groups of nodes will be defined in predefined areas
- The results obtained in the research will focus on the routing performance of the MANET
- Issues in other layers will not be discussed and will be considered except where it relates to the MANET routing protocol

1.6 Research Methodology

The methodology of research performed was based on network modeling and simulation. The Network Simulator-2 (VINT Project, 1995) was utilized to evaluate existing and proposed MANET routing protocols taking into account of the non-uniform distribution of nodes in a given geographical area. The models and routing protocol enhancements were refined successfully based on preliminary results. To verify the validity of the implementation, a second round of simulation was performed and the observation of the implementation was recorded. The justification of the enhancement was then evaluated through a series of graph derived from the simulation results. Finally a discussion and analysis on the results obtained was conducted.

Chapter 5 analyses and discusses gathered results from the simulation. A comparison of the individual routing is performed to provide a clearer picture on how improvements on the protocols is achieved

Chapter 6 summarizes the entire thesis up to what has been achieved and provides insights on the research contributions.

CHAPTER 2 LITERATURE REVIEW

2.1 Mobile Ad Hoc Networks in General

A mobile ad hoc networks (MANET) consists of a group of wireless nodes communicating with each other through multiple-hop wireless links and without any additional infrastructure. Each node in the network is self managed, acting as a router and host simultaneously. Nodes are also expected to forward routing information and packets to other adjacent nodes within its transmission range (MANET, 1997). The network topology is very unpredictable and the number of nodes within a network could change significantly within a short period of time. However, research efforts to improve mobile ad hoc wireless network performance have intensified in recent years as portable and mobile devices become more commonplace. Future ubiquitous and wireless networks will have to consider factors such as mobility, different levels node densities and volatile network sizes which is expected to be changed over certain periods.

A lot of research has been conducted in recent years to actualize the vision of a dynamic infrastructureless network. The objective of such networks is to improve end to end communication for wireless environments by relaying data packets across the network via intermediate users. Studies of the TCP/IP architecture showed that TCP/IP requires some modifications to function efficiently in such networks (Albohasan et al., 2004). The paper by (J. Broch et al., 1998) evaluates the performance of MANET routing protocols and their derivatives. The protocols were be classified into two major categories -- Table Driven or Proactive vs. On Demand or Reactive.

protocols would consume bandwidth with update information of the network even when there are no active data transmissions occurring.

2.2 Common MANET Routing Algorithms

A few of the popular routing algorithms for MANETs include distance vector algorithms, link state and also source routing algorithms (Perkins et al. 2003), (Johnson et al. 1996) and (Jacquet et al 2003). A well known distance vector based Proactive routing algorithm is the Destination Sequence Distant Vector (DSDV) protocol, while an example of distance vector based Reactive protocol is Ad Hoc On-Demand Distance Vector (AODV). Distance vector algorithms require each node to maintain a set of distances which includes a set of neighbors over a certain range defined by the number of hops. Periodic updates on the neighbor distances provide up to date information regarding the closest neighbors and determination of the shortest path taken to the destination.

Link State algorithms are used in Global State Routing (GSR) (Chen, 1998), Fish Eye Routing (FSR) (Albohasan et al. 2004) and Optimized Link State Routing (OLSR) (Jacquet et al, 2001). The link state approach to routing requires the nodes in the network to acquire the routing information of other nodes in the network via periodic updates among the nodes. The information would usually be flooded over the entire network regardless of whether there are active transmitting links. Upon receiving the link state information a shortest path algorithm will be applied at each node for selecting the route towards the destination.

bandwidth is expected to be lower. Nodes that are confined in certain known areas would not have to update their routing information.

2.2.1 Ad Hoc on Demand Distance Vector Protocol (AODV)

Ad Hoc on Demand Distance Vector (AODV) protocol (Perkins, 2003) is reactive ad hoc wireless protocol that is able to support unicast, broadcast and multicast data transmission. AODV uses the next hop routing model with sequence numbers and periodic beacons to discover routes and maintain them. These features were borrowed from DSDV (Destination Sequenced Distance Vector) routing protocol (Perkins, 2003). AODV uses Route Discovery and Route Maintenance as basic mechanisms for establishing links among nodes.

AODV Route Discovery is required when the node has data to send. A link to the desired destination must be established before any upper layer communications could take place. Route Discovery begins with a route request (RREQ) message containing information such as the destination node's IP address, sequence number, hop count and broadcast ID. These attributes are sufficient for identifying the destination node; therefore if a non destined node receives the message it will automatically forward it until the message reaches its intended recipient. A route reply (RREP) will be sent back to the message source using the reverse route obtained from the RREQ message, otherwise a new route has to be determined using the Route Discovery mechanism if no route exists.

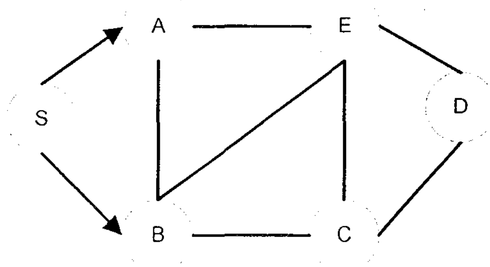

Figure 2.2 A Route Request Cycle for AODV during Route Discovery

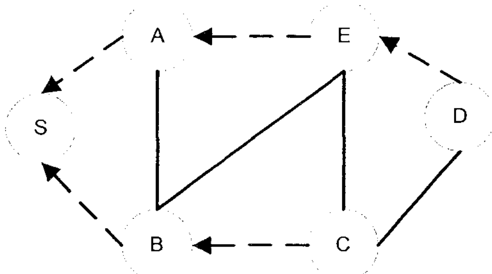

Figure 2.3 A Route Reply is sent from the destination back to the source

Route Maintenance is required by AODV to ensure that the selected or discovered routes are fresh (current), up to the point where the sender is initiating upper layer communication. HELLO messages are used by the next hop neighbor to perform the Route Maintenance by sending the HELLO message back to the upstream nodes. On the event that link is broken a route error (RERR) packet would be sent back to the source node to notify the failure. The source node would then issue new RREQs in an attempt to reestablish the link. To reduce the amount of RREQ packets flooding the network in the event of any failed links, an optimization technique is introduced. The technique uses the Expanding Ring Search (Hasan, 2004) to locate other alternative paths to replace a failed link.

Even with the introduction of the Expanding Ring Search or localize query repair (S.-J. Lee et al. 2003) there remains doubts on the effectiveness of the AODV being implemented on a more practical basis. The implementation of the AODV-UU by Uppsala University (AODV-UU, 2006) was good enough for small local area networks but is yet to be tested on more volatile environments.

Internet connectivity has also been implemented with the AODV routing protocol. Various studies have been using AODV to create direct connectivity between MANET and the Internet. One of which is the implementation of Network Mobility (NEMO) protocol (PÄÄKKÖNEN, 2004). Upper layer protocols like MIPv6 have been implemented into the architecture to offer mobile IPv6 connection to the internet while routing using AODV in the local area network. The research concluded that MANET and NEMO approaches enabled end to end connectivity of mobile ad hoc networks. Other issues of auto-configuration of addressing in MIPv6 and AODV were discussed as well.

2.2.2 Optimized Link State Routing (OLSR)

Optimized Link State Routing (OLSR) (Jacquet, 2001) was developed as a point to point protocol that utilizes the link state routing algorithm. The OLSR is basically a proactive protocol which updates its routing information periodically. The algorithm proposed in this protocol requires each node in the network to possess information of the network and exchanges them periodically to keep each other up to date. This design promotes the reduction in the number of control messages exchanged during the route discovery period. The idea is to allow nodes to acquire information about one another through a certain period thus minimizing the thrashing of the routing cache. The technique to achieve this is to employ a Multipoint Relaying strategy (MPR) where in every topological update each node in a network will have to transmit its information to a neighboring set of nodes and the packet will be retransmitted into other parts of the network. However, other nodes that are not included in the set will not retransmit but they are eligible to store and process its information. The retransmitting nodes are known as known as multipoint relays of a transmitting node (P. Jacquet et al, 2003).

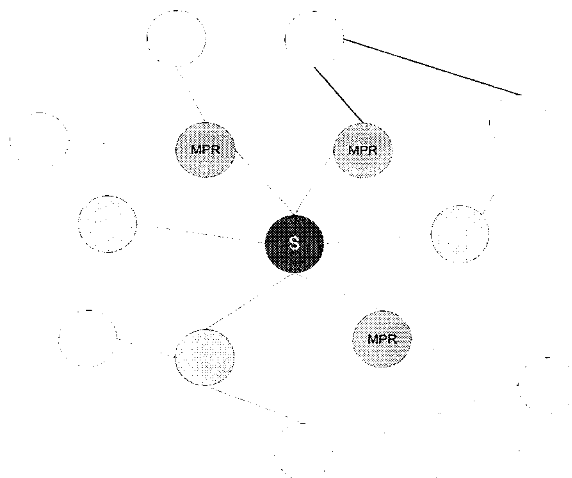

Figure 2.4 MPR selection strategies in OLSR routing protocol.

To select the MPR nodes each node will have to periodically broadcast HELLO messages with a list of its one hop neighbors. The HELLO messages are known as Topology Control (TC) messages. The receiver of the HELLO messages will select a subset of one hop neighbors which will complete all of the two hop neighbors in the network. With such information in hand, the node will be able to determine an optimal route based on the number of hops with the information provided by its neighbors. The topology information is stored in the routing table and when data transmission begins the nodes will have the route information at their disposal.

Being a Proactive type of a routing protocol OLSR is expected to manage the routing traffic better than its Reactive counter parts given that there was minimal node movements inside the network. The performance of OLSR is affected when the network consists of constantly moving nodes that are going in and out of each others network transmission range. However OLSR is expected to perform better in the presence of large number of nodes (Aleksandr Huhtonen 2004). Again, it would be more practical if these broadcasts were to be adjusted to fit the network size.

2.3 Comparisons of MANET protocols

Comparison studies using metrics such as Packet Delivery Ratio, Throughput, Dropped Packets, Routing Overheads and Path Optimality have been conducted on various MANET protocols. The study by (J. Broch et al, 1998) focuses on the comparison between Reactive and Proactive protocols. Four MANET routing protocols were tested in similar environments. Proactive protocols such as DSDV did not measure up to the performance of its reactive counterparts such as AODV and DSR (Dynamic Source Routing) in terms of packet delivery and routing overheads. The paper concluded that Reactive MANET routing protocols performed better for networks that were more dynamic and experienced high node mobility.

In the paper by S.R. Das et al. (S.R. Das et al, 2000), DSR and AODV were compared against each other. The author highlighted the usefulness of promiscuous listening which allows DSR to possess a greater amount of routing information compared to AODV. Therefore AODV needed to perform more route discoveries compared to DSR in a similar environment. On the other hand, AODV could almost always ensure that the selected route was fresher since the selection of routes is determined based on the most recent routing entry.

A study by (Nilsson, 2004) showed that reactive MANET protocols perform relatively better that table driven or proactive routing protocols in terms of incurring overheads and freshness of routing information in highly dynamic MANET. However despite the link-state nature of OLSR the amount of throughput achieved and packets delivered is relatively high for proactive routing protocols.

Another comparison study was made between AODV and OLSR (Huhtonen, 2004) in terms of scalability, security considerations and resource usage. The comparison was made between the architecture of the two ad hoc routing protocols. OLSR was deemed to perform better in networks with high node density and a high frequency of data transmissions. Other issues such as scalability are shown to be a challenge for both types of routing protocols. Security issues however favor AODV as it was observed to be able to integrate with more complex cryptographic solutions. That paper provided an overview of the difference between proactive distance vector protocols versus reactive link state routing protocols, but detailed performance comparisons were not presented. The paper also showed that AODV were more robust against topological changes compared to OLSR.

Table 1.1 Comparison of MANET routing protocol

Protocol	Routing	Network Size Scalability	Routing Overheads	Robustness against topology change
AODV	Reactive	Moderate	Low	Good
OLSR	Proactive	Moderate	High	Bad

Consequently, one representative from each category of proactive and reactive MANET routing protocols namely OLSR and AODV, would be included in the comparison study of this thesis to evaluate their performance in environments with different node densities. The selection was based on the fact that there were extensive studies performed to evaluate each protocol's scalability and there were discussion on node density issues for both protocols (Nilsson, 2004). The existing MANET routing protocols will then be compared to the proposed new MANET routing protocol in terms of their performance in non-uniform density topologies.

2.4 Node Density Issues

2.4.1 *DENSE* and *SPARSE* Regions

The optimum density of MANET was studied in (Royer, 2001), which discussed the tradeoffs between network density and node connectivity in the face of increasing node mobility, and proposed a search for an optimal node density value for maintaining connectivity in a stationary network. However, the results were inconclusive regarding the optimal density for maintaining connectivity in highly mobile environments. When neighbor nodes are saturated they yield almost similar results. Nonetheless, (Royer, 2001) concluded that both transmission power and the node densities need to increase when nodes experience increasing mobility if connectivity were to be maintained.

The node density for an entire network can be identified as the number of nodes that populate over a certain area or region of a MANET. Therefore the node density can be equated to:

ρ *Node Density*

n *Number of nodes*

A *Size of Network Area*

$$\rho = \frac{n}{A}$$

(Equation 1)

The relationship of the node density in MANET should to consider the extent of the nodes transmission range covering the network area. Including the transmission range coverage of the nodes will provide a better estimation for node density as it will help identify how well the network is connected. In a large network area, even though that there are many nodes scattered around but if the nodes are far from each others transmission range then we would not be able to say that the network is *DENSE*. Therefore the network area has taken into account the transmission range to provide a better estimate of node density.

2.4.2 Connectivity and Connection Probability

The probability of connectivity is defined based on the homogenous transmission range of the nodes which is denoted as *P(k-con)* (C. Bettstetter, 2002). The definition of connectivity of a network by is defined by the following:

- The number of neighbors surrounding a node is denoted by its degree d.
- A node that has a degree $d = 0$ is said to be isolated from the rest of the network.
- The minimum degree of nodes $d_{\min}$ and is considered as the smallest degree of all nodes in the network
- A network is said to be connected when every pair of nodes exists a path between them, otherwise it is disconnected.
- A connected network always has a minimum degree $d_{\min} > 0$ but the reverse implication is not necessarily true, hence this is just an estimate.
- A network is k-connected if for each pair of node exists at least k mutually independent paths connecting them.

The formula for *P(k-con)* proposed in (Bettstetter, 2002) :

$$P(k\text{–}con) = \left(1 - e^{-\mu}\sum_{i=0}^{k-1}\frac{\mu^i}{i!}\right)^n$$

(Equation 2)

The connection probability of *P(k-con)* could also be derived from transmission radius of a single node r_0 in (Bettstetter, 2002) with the assumption that the network have at least one mutually independent path connecting to the node in a given area, formulated as *P(1-con)*. The derivation of *P(1-con)* is as follow:

$$r_0 \cong \sqrt{\frac{\ln(1-P(1-con)^{1/n})}{-\rho\pi}} \qquad \textit{(Equation 3)}$$

$$r_0^2 = \frac{ln\ (1-P(1\text{-}con)^{1/n})}{-\rho\pi}$$

$$\rho\,\pi\,r_0^2 = ln\ (1-P(1\text{-}con)^{1/n}) \qquad \textit{(Equation 4)}$$

Given $\mu = \rho\,\pi\,r_0^2$, *substituting into (2)*

$$\mu = ln\ (1-P(1\text{-}con)^{1/n})$$

$$e^{-\mu} = 1-P(1\text{-}con)^{1/n}$$

$$P(1\text{-}con)^{1/n} = 1-e^{-\mu}$$

$$P(1\text{-}con) = (1-e^{-\mu})^n \qquad \textit{(Equation 5)}$$

The denotation of the variables used to derive *P(1-con)* from the are as follow:

- r_0 (Radius of the transmission area)
- n (Number of nodes)
- A (Area of the network)
- ρ (Physical node density equivalent to n/A)

The variable ρ equivalent to the node density of the network, the node density is also taking into account the transmission range which is denoted by $\pi\,r_0^2$. The transmission range coverage is assumed to be similar for all nodes therefore it is multiplied by the number of nodes n. Thus the variable μ is the size of the transmission coverage over the size of the network area giving a node density estimate based on the transmission range of node and not just the number of nodes itself.

In this thesis the focus is in determining at least one viable route interconnecting a source to a destination within the MANET. Therefore, the value of *k* is set to 1 to identify that the network at least one mutually independent path connecting the nodes in a given area. This means that in any particular network that has a high degree of node density has the connection probability of *P(1-con)*. Thus there is at least one mutually independent path connecting the nodes in the particular network area. Such network is categorized as *a.s* (almost surely) 1-connected with the connection probability of 0.95 or higher (*P(1-con)* $\geq$ 0.95) based on the definition of (Bettstetter, 2002).

2.4.3 *SPARSE* and *DENSE* Region definition

The calculation on the degree of node density of the network areas in this study will be based on the formula provided for *P(1-con)*in *Equation 5.* Based on *P(1-con)* two levels node density are identified, *DENSE* and *SPARSE.* The definitions for the two levels of node density are defined.

The node density of the MANET region are considered to be *DENSE* based the following conditions:

- It has at least one mutually exclusive path to other nodes in the same area that is independent of one another.
- *P(1-con)* $\geq$ 0.95.

The node density of the MANET region are considered to be *SPARSE* based the following conditions: