SELF ADAPTIVE RESOURCE AWARE ROUTING PROTOCOL FOR DELAY TOLERANT NETWORK

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To my mother, father, wife, and my son Sheikh Dayyan Haider.

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ABSTRACT

Delay Tolerant Network (DTN) is a kind of network that is still operating even though there is no end-to-end path between source and destination due to network partitioning, small transmission range, mobility and frequent shutdown of interlinked nodes. The probabilistic protocol has been used which observes the encountering history to meet message destination and does not account for the resource availability and quality of node to carry messages. As a result some messages are dropped before reaching destination which reduce message delivery. This thesis presents Self Adaptive Resource Aware Routing Protocols for DTN in which message transmission criterion is based on buffer space and quality of node to carry received messages. The proposed protocols have been categorized as self adaptive resource aware routing protocols and self adaptive quality aware routing protocols. In self adaptive resource aware routing protocols the buffer space has been taken as scarce resource. Two resource aware routing protocols known as DF++ (an Adaptive Probabilistic Buffer Aware Routing Protocol) and Connection Frequency Buffer Aware Routing Protocol (CFBARP) have been proposed that are capable to forward message by observing buffer space of receiver. A Forwarding Impact Aware Routing Protocol (FIAR) has been presented in which resource consumption has been reduced by prioritizing message transmission priorities and message drop. The priorities are assigned to make a fair selection to transmit and drop a message. The self adaptive quality aware routing protocols use additional parameters to increase the ability of node to carry messages by using novel metrics known as Transmit Factor, Drop Factor, and hop away count. The two routing protocols known as Contact Quality Based Routing Protocol (CQBRP) and Threshold Based Locking Routing Protocol (TbL) have been addressing the quality of node. The TBLRP further reduces message transmission by using novel locks called Transmission Lock and Drop Lock. The simulation results have proven better message delivery and reduced message transmission under real time mobility traces such as Sassy and Helsinki Finland city. On average, CQBRP has reduced 50% message transmissions and increased 57.75% message delivery. The TbL has reduced 44% transmissions and increased 50% message delivery. The CFBARP has increased 37% message delivery while DF++ has reduced 75% message transmissions. Finally, FIAR has reduced 82% message transmissions.

ABSTRAK

Rangkaian Boleh Terima Lengah (DTN) adalah sejenis rangkaian yang masih beroperasi walupun tidak ada laluan yang menghubungkan nod asalan dan destinasi disebabkan oleh pemetakan rangkaian, julat pemantulan yang kecil,kemudahalihan dan kerapnya berlaku pemutusan dalam jaringan diantara nod-nod. Protokol berkebarangkalian memerhati sejarah pertemuan dengan destinasi mesej tetapi tidak mengambil kira ketersediaan sumber dan kualiti nod dalam membawa mesej-mesej. Ini menyebabkan sebahagian mesej-mesej dibuangk sebelum sampai ke destinasi dan mengurangkan kadar penghantaran mesej-mesej. Tesis ini mempersembahkan Protokol Penghalaan Boleh-Sesuai Sendiri dan Sedar-Sumber untuk Rangkaian Boleh Lengah di mana kriteria penghantaran mesej adalah berdasarkan ketersediaan sumber seperti ruang penimbal dan kualiti nod untuk membawa mesej-mesej yang diterima. Beberapa protocol dicadangkan telah dikategorikan sebagai Protokol Penghalaan Boleh-Sesuai Sendiri Sedar-Sumber dan Protokol Penghalaan Boleh-Sesuai Sendiri Sedar Kualiti. Bagi Protokol Penghalaan Boleh-Sesuai Sendiri Sedar Sumber, ruang penimbal dianggap sebagai sumber yang meruncing. Dua protokol Sedar-Sumber yang diberi nama DF++ (Protokol Penghalaan Berkebarangkalian Penimbal-Sedar Boleh-Sesuai), dan Protokol Penghalaan Penimbal-Sedar Kekerapan Pertemuan (CFBARP) telah dicadangkan yang berupaya untuk menggerakkan mesej selanjutnya dengan melihat kepada ruang penimbal penerima. Protokol Penghalaan Sedar Kesan Penghantaran (FIAR) juga dipersembahkan di mana penggunaan sumber telah dapat dikurangkan dengan menyusun keutamaan pemantulan mesej dan pembuangan mesej. Keutamaan-keutamaan diberi supaya pemilihan yang adil dapat dibuat dalam memantul dan membuang mesej. Protokol Penghalaan Boleh-Sesuai Sendiri Sedar Kualiti pula menggunakan parameter-parameter tambahan yang dikenali sebagai Faktor Pantulan, Faktor Pembuangan dan Pengira Kejauhan Hop dalam meningkatkan keupayaan nod membawa mesej. Dua Protokol Penghalaan yang dinamakan Protokol Penghalaan Berasaskan Kualiti Hubungan (CQBRP) dan Protokol Penghalaan Berasaskan Had (TbL) yang dicadangkan mengambil kira kualiti nod. TbL mengurangkan penghantaran mesej menggunakan Had Pantulan dan Had Pembuangan. Hasil simulasi telah membuktikan penghantaran mesej yang lebih baik dan pengurangan pantulan mesej di bawah jejak-jejak mudahalih sebenar Sassy dan Bandar Helsinki dapat dicapai. Puratanya, CQBRP mengurangkan 50% pantulan-pantulan mesej dan menambahkan 57.75% penghantaran mesej. TbL mengurangkan 44% pantulan-pantulan mesej dan menambahkan 50% penghantaran mesej. CFBARP menambahkan 37% penghantaran mesej sementara DF++ mengurangkan 75% pantulan-pantulan mesej. Akhirnya, FIAR Kesan Penghantaran mengurangkan 82% pantulan-pantulan mesej.

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LIST OF ABBREVIATIONS

M	–	Message
M_{size}	–	Message Size
ni,nj	–	Nodes ni and nj
B_{avail}	–	Available Buffer Space
B_U	–	Buffer Used
C_{buffer}	–	Current Buffer
SSUM	–	Self Statistical Update Module
NSUM	–	Neighboring Statistical Update Module
QUM	–	Quality Update Module
CQS	–	Contact Quality Scheduler
TMT	–	Total Message Transmitted
TMR	–	Total Message Recieved
TMD	–	Total Message Dropped
ET(ni,nj)	–	Encounter time since node ni last saw node nj
TCV	–	Transmit Count Vector
RCV	–	Recieve Count Vector
DCV	–	Drop Count Vector
TC	–	Transmit Count
DC	–	Drop Count
RC	–	Recieve Count
TF	–	Transmit Factor
DF	–	Drop Factor
MCQ	–	Message Current Quality
CFBARP	–	Connection Frequency Buffer Aware Routing Protocol
HaV	–	Hop Away Vector
REV	–	Recent Encounter Vector
QI	–	Quality Impact
TR(i,j)	–	Transmission range of node ni,nj

CHAPTER 1

INTRODUCTION

1.1 Overview

Recent advancements in communication technologies (Ariyavisitakul, 2000; Bansal *et al.*, 1999) made it possible for seamless interconnections between mobile nodes and providing innovative ways for peoples to interact within a community as well as between communities. Mobile applications such as social networking, wildlife monitoring (Pelusi *et al.*, 2006; Juang *et al.*, 2002), terrestrial mobile networks (Vinayakray-jani and Sanyal, 2012), vehicular ad hoc networks (VANETs), military (Lu and Fan, 2010), and sensor networks are becoming more challenging (Daly and Haahr, 2010) due to high disruptions between source and destination caused by mobility of nodes. These applications suffer frequent disconnections and end-to-end path is highly unstable and may change or break soon after it has been discovered. Ad hoc protocols like table-driven (Reddy *et al.*, 2006) and on-demand (Perkins and Royer, 1999; Johnson and Maltz, 1996) are not able to perform well because the assumption of end-to-end path is made prior to transmission of data. In addition, mobile devices are equipped with limited network resources such as buffer space, bandwidth, energy, and processing power.

Delay Tolerant Network (DTN) (Fall, 2003) is a type of network in which connectivity between nodes could be intermittent and/or disrupted due to dynamic topology change, network partitioning, mobility, or a short transmission range of nodes. Moreover, the source and destination cannot sustain an uninterrupted end-to-end path. DTN routing protocols (Gong and Yu, 2013; Bulut and Szymanski, 2010) use provisional end-to-end connectivity and transmit a message over existing links by adopting a paradigm known as store, carry, and forward. Accordingly, each node stores the incoming message in its buffer, carrying it while moving, and forwards it when coming within communication range of other nodes. The messages reach to their destinations via these hop-by-hop transmissions.

Based on their transmission mechanism, DTN routing protocols (Jain *et al.*, 2004; Mingjun and Liusheng, 2009) can be grouped into Single-Copy or Forwarding Based, and Multi-Copy or Replication Based. The Single-Copy protocols (Spyropoulos *et al.*, 2008b) forward unique copy of message along a single path. For example, Direct Delivery protocol carries source messages and delivers only when it comes within the transmission range of destination node. Single-Copy protocols consume fewer network resources but increase delivery delay. Moreover, a message delivery fails when a node drops message somewhere in path due to full capacity of buffer space.

DTN Multi-Copy routing protocols (Vahdat *et al.*, 2000; Spyropoulos *et al.*, 2009; Balasubramanian *et al.*, 2007; Spyropoulos and Picu, 2013) forward unlimited copies of each message. For instance, in Epidemic protocol, each message copy is flooded on all encountered nodes. This gives various paths for a message to reach its destination at large consumption of resources such as buffer space, energy, and bandwidth. It is not possible to equip mobile nodes with unlimited resources, and an alternative solution is required to control resource consumption.

Resource usage may be controlled by limiting number of message copies. This concept led to an era of quota based routing protocols, probabilistic routing protocols, social routing protocols, self adaptive routing protocols and control flooding routing protocols. In quota based routing protocols such as Spray and Wait, each node is given quota to transmit n number of message copies. A node starts by forwarding n message copies across its neighbors in what is known as the Spray phase. If a destination is not found, then the Wait phase starts in which each node is allowed to deliver message directly to its destination. Since the mobility pattern of each node varies, and messages may be sprayed on nodes not moving in the direction of the destination, more networking parameters must be observed before making a forwarding decision. This is implemented by probabilistic routing protocols, social routing protocols and self adaptive routing protocols.

Probabilistic routing protocol such as PRoPHET protocol (Lindgren *et al.*, 2004) has used a network parameter as a metric known as delivery predictability. The predictability value determines the ability or suitability of node to encounter a message destination. A node with a high probability of encountering a message destination is considered suitable to carry that message. The probability value is computed by observing encountering history, transitive connectivity and aging. The encountering history determines the frequency of node encounters. Transitivity connectivity states that if node ‘a’ is likely to meet ‘b’, and ‘b’ is likely to meet ‘c’, then ‘c’ is best carrier to receive a message destined to node ‘a’. Similarly, the aging was used to decrease the node probability based on time since nodes have not seen each other. The probabilistic routing protocol takes more network parameters to analyze the accuracy of a node. This thesis is aimed at addressing the following improvements in probabilistic routing protocol:

i. The probabilistic protocol observes delivery predictability and cannot perform well in environments where traffic pattern and mobility of node changes dynamically. For instance, consider a node as a city bus having high probability values to encounter a plaza, cafeteria or bus station at time t1, t2 and t3. In normal mobility, bus carry and deliver messages to these locations and increases the delivery ratio. However, a traffic jam can cause delay and bus cannot reach the locations for which it is having high predictability value. Meanwhile, bus continues to receive messages due to its high probability. Since the buffer is finite, therefore, bus drop its carried messages to overcome congestion. The message drop reduces the delivery ratio because the bus was carrying dropped messages due to its high probability value to encounter their destinations. As there are multiple copies of each message, the same bus may receive the dropped messages from other parts of network. The retransmission produces more overhead and consumes buffer space and node energy. The probabilistic routing protocol does not observe the current behavior of a node in terms of its ability to carry the message.

ii. The probabilistic routing protocol observes predictability and does not consider the number of hops a high probable node is away from message destination. The hops are intermediate nodes on the way to destination. For instance, if a destination is one node away from source then it is called one hop away. The increase in intermediate nodes decreases the message delivery. This is due to drop caused by incoming messages from on the way nodes . Hence, it is vital to observe the number of hops a node has moved away from message destination.

iii. In probabilistic routing protocol, a node always forwards a message to a high probable node and does not account for available buffer space at the receiver. Hereby, the receiver node cannot carry all incoming messages. The previous work has considered buffer space as unlimited resource and nodes were anticipated to carry all received messages. Since DTN is a resource scarce network in which buffer space is limited, therefore, adaptive routing protocols (Liu and Wu, 2009; Wang *et al.*, 2009) are required to operate under finite buffer space.

This thesis is addressing the Self Adaptive Resource Aware Routing Protocols (Chen *et al.*, 2014) in city based environments where disconnections are frequent due to obstacles in communication path and mobility of nodes. Self Adaptiveness has been defined as the self-ability of a node to change its transmission behavior without human intervention. The proposed protocols have been categorized as Self Adaptive Resource Aware and Self Adaptive Quality Aware. Self Adaptive Resource Aware Protocols define a message transmission mechanism under finite buffer space. The Self Adaptive Quality Aware Protocols use novel metrics known as Transmit Factor and Drop Factor to compute Quality Value (QV) of nodes. The Quality Value (QV) determines ability of node to carry message. The performance of existing and proposed protocols have been analyzed under real time traces in terms of minimizing the number of transmission, message drop, delivery delay and overhead, while increasing probability.

1.2 Delay Tolerant Network (DTN)

Ad hoc proactive routing protocols (Clausen *et al.*, 2003) continuously maintain the path information about its known destinations in routing tables, whereas reactive routing protocols (Perkins and Royer, 1999; Johnson and Maltz, 1996), TORA (Park and Corson, 1997) establish routes on the request of the application. This condition is not possible in applications suffering frequent disconnections or disruptions. More precisely, reactive protocols may not be able to find the complete end-to-end path while proactive protocols are not able to maintain the routing tables.

Delay Tolerant Network (Fall, 2003) provides communication architecture in situations in which connectivity among nodes is intermittent and/or disrupted due to dynamic topology changes, network partitioning, node mobility, and short transmission range. As a result, source and destination cannot sustain the uninterrupted end-to-end connectivity and connections between nodes are provisional. Applications such as vehicular networks (Zhao *et al.*, 2012; Shin *et al.*, 2012), vehicular sensor networks (Li *et al.*, 2008), urban area networks (Pham and Fdida, 2012), deep space communication (Mukherjee and Ramamurthy, 2013; Tsao *et al.*, 2010), military networks, and off-line message servicing are attributed to such exceptions.

The DTN routing protocols (Sujin-shu *et al.*, 2010) use short-term end-to-end connectivity and transmit a message over existing links by adopting a paradigm known as store, carry, and forward. Accordingly, a node stores an incoming message in its buffer, carries it while moving, and forwards it when move in the transmission range of other nodes. Figure 1.1 shows the operation of DTN based application where source S holds a message for destine D. Since a direct end-to-end path is not available, S forwards the message to available node X at time t1. The node X carries message while moving and forwards to Z at time t2. Finally, node Z transmits the message to destination node D at time t3.

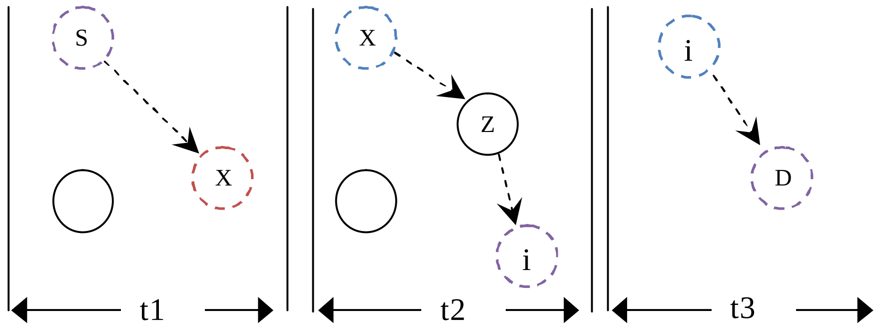

Figure 1.1: DTN store, carry and forward mechanism

1.2.1 The Applications of Delay Tolerant Network

In Delay Tolerant Network, nodes exchange information in opportunistic way. The opportunistic (Sandulescu and Nadjm-Tehrani, 2008) means that nodes have no information about the further availability of contact. This characteristic makes DTN a powerful tool for large number of ad hoc network applications. This section has summarized most commonly used application for DTN.

1.2.1.1 Sensor Network

In Sensor Network (Sohrabi *et al.*, 2000; Wang and Wu, 2007; Zhou and Zhang, 2013; Abdelzaher and Han, 2013), the sensor nodes communicate with data collector stations via intermediate nodes. If communications infrastructure is not available then large amount of sensors needed to be deploy to provide end-to-end connectivity. The installation of large number of sensor is not viable due to cost. The DTN store, carry, and forward paradigm may be used in which sensor nodes store data in buffer for some time and transmit when connection becomes available.

Figure 1.2 shows a sample application in which two sensor networks such as the Region A and B have been connected in an application via DTN gateway. The application data is buffered at sensor and transmitted upon connection availability available.

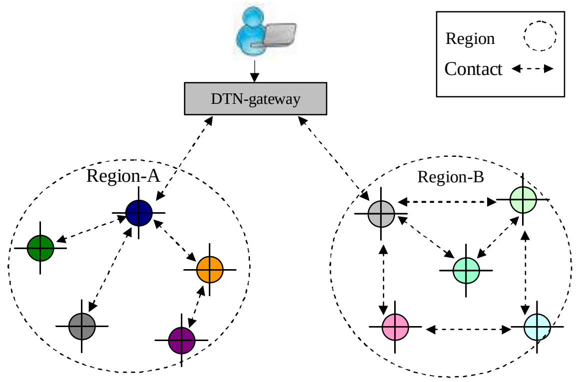

Figure 1.2: Two sensor network connected via DTN gateway

1.2.1.2 Deep Space Communication

Deep Space Communication (Ha, 1986; Akan *et al.*, 2002; Akyildiz *et al.*, 2003) from Earth to space craft may suffer propagation delay due to the long distance. Therefore, an appropriate solution is required to handle such delays and disconnections. Furthermore, security is also needed for such applications (Farrell and Cahill, 2006; Farrell *et al.*, 2009). Figure 1.3 shows the sample communication scenario of satellite between Mars and Earth.

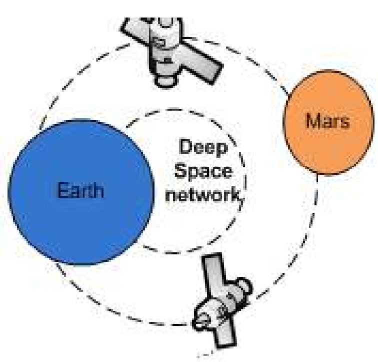

Figure 1.3: Deep space communication

1.2.1.3 Off-line Message Servicing (OMS)

The DTN architecture is suitable for Off-line Message Servicing (OMS). Consider the scenario in Figure 1.4 in which sender S has received a message M from R for destination D. At present, D is shut down and is not active. In this case, S stores M in its buffer and delivers it to D upon becoming available. Internet e-mail, SMS, and MMS are examples of Off-line Message Servicing (OMS).

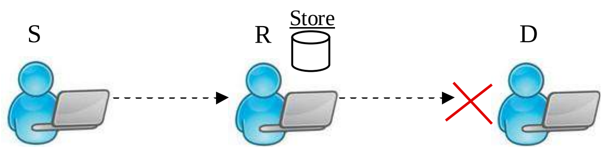

Figure 1.4: Off-line message servicing

1.2.1.4 Underwater Communication

Sound-based Underwater Communication (Akyildiz *et al.*, 2005) is relevant to applications like deep-sea sensor networks or military/civilian submarine communication. In combat situations, communication must be avoided and long delays may occur until a certain message is delivered. On the other hand, underwater communication has a limited communication range at several kilometers maximum. Figure 1.5 depicts a sample scenario in which a submarine has been collecting the data from sensors.

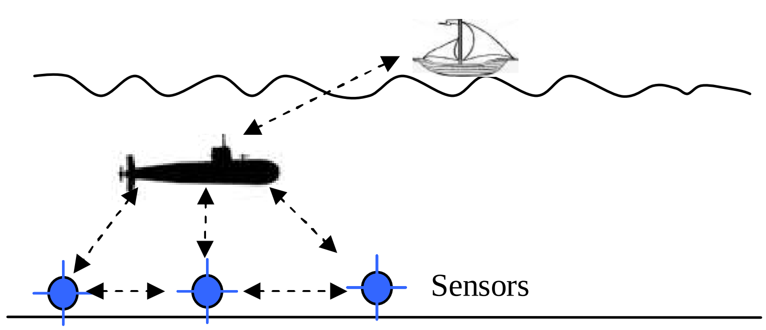

Figure 1.5: Underwater communication

1.2.1.5 Urban Area Network

Along with the importance of DTN applications in inter planetary networks (IPNs), it can be very useful for Urban Area Communication as well (Conti and Giordano, 2007; Doering *et al.*, 2010; Quadri *et al.*, 2011). For example, as shown in Figure 1.6, a urban area network may be composed of buildings equipped with communication devices and Base Stations. Vehicles and pedestrians act as mobile nodes moving randomly at different speeds and causing dynamic network partitions. Hence, store, carry and forward architecture can be used to facilitate the transmission of messages over dispersed and disconnected Regions.

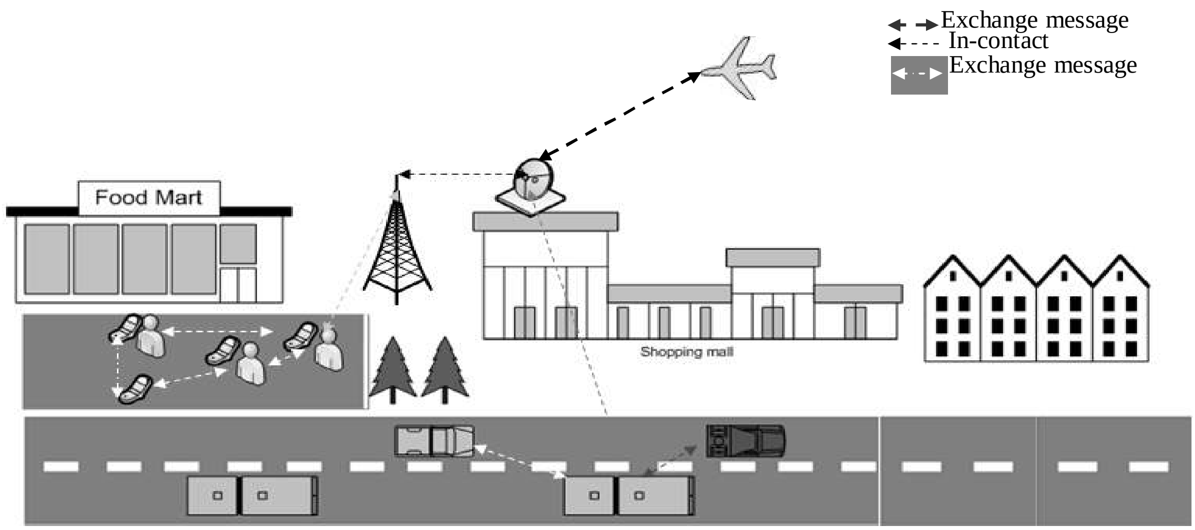

Figure 1.6: Urban area network

1.3 Background of the Problem

DTN Multi-Copy Flooding based routing protocols (Vahdat *et al.*, 2000; Wu *et al.*, 2013) transmit several copies of each message across all available contacts. Moreover, each message has multiple paths to reach its destination. Multi-copy flooding routing protocols reduce end-to-end delay and increase delivery ratio but require high buffer space to accommodate messages, high bandwidth for message transmission, and high energy levels to transmit and receive messages.

In order to understand resource usage, consider the snapshot shown in Figure 1.7 in which mobile node pedestrian S holds a message for destination mobile node D and the transmission range of S is not large enough to establish direct connectivity with D. Hereby, according to DTN Multi-Copy flooding based routing protocol, pedestrian S will transmit message copy to all neighbors such as R1, R3, R4, and C1 at time T1. The C1, while carrying the message, transmits it on all in-contact nodes at time T2. Finally, C1 delivers the message to destination D at time T3. It can be seen that message was replicated on nodes even they were not moving in direction of destination. Such transmissions overload buffer space and energy of node. As DTN is a resource scarce environment, therefore, Multi-Copy flooding routing protocols are not viable and an alternate solution is required to control resource consumption.

One solution to minimize resource consumption is by restricting the transmission of message copies. The quota based routing protocols (Spyropoulos *et al.*, 2005b; Soares *et al.*, 2012; Zhang and Luo, 2012) control the transmission of message copies to n number of transmissions. For instance, in the Spray and Wait routing protocol, a node starts by spraying n message copies around its neighbors. This is known as the Spray phase.

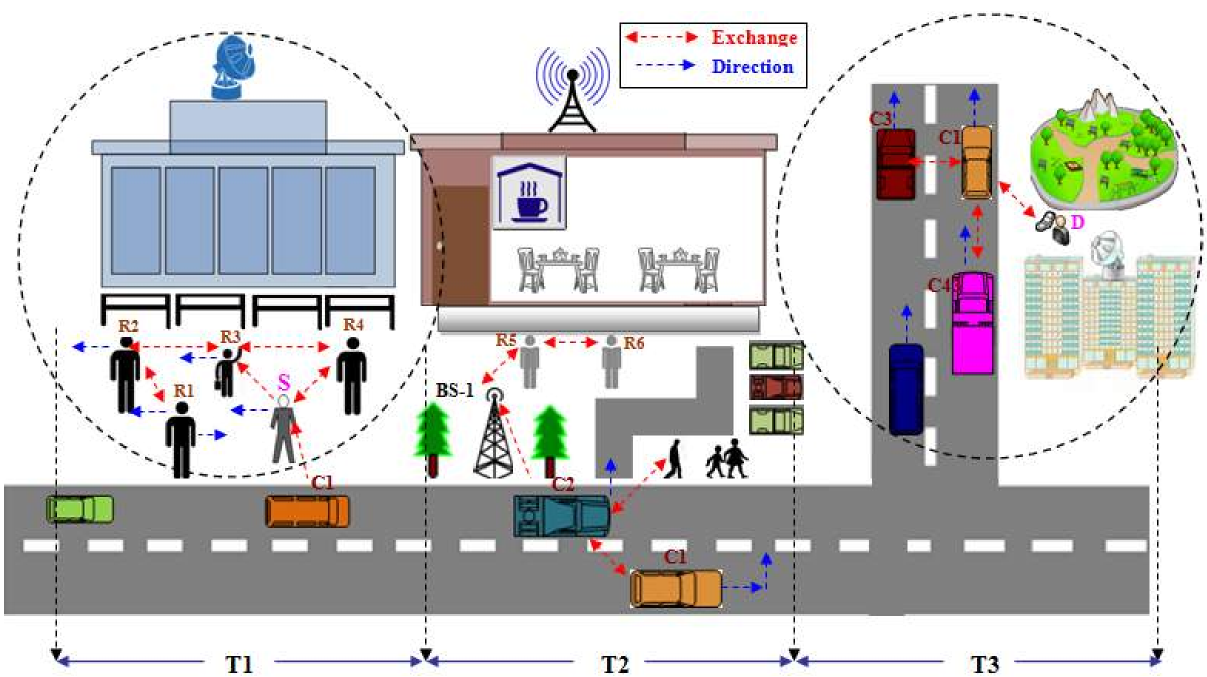

Figure 1.7: Message replication of flooding routing protocols

If the destination is not found in Spray phase, then the protocol shifts to a Wait phase in which each node is allowed to deliver the message directly to the destination. However, the Spray and Wait protocol does not utilize other network parameters such as movement patterns and encounter history. The probabilistic routing protocol (Lindgren *et al.*, 2004) further optimizes network throughput by observing characteristics of the node in terms of encountering history. The message forwarding decision involves a metric known as delivery predictability. Accordingly, the source transmits a message only if a receiver is likely to meet its destination. A node is highly probable only if it holds high encounter frequency with message destination. The probabilistic routing protocols improve network throughput in terms of increasing delivery probability and reducing message transmissions. However, there are certain scenarios in which probabilistic routing protocols begin to perform poorly and resource consumption becomes equivalent to Multi-Copy flooding routing protocols. These sections have elaborated an improvement of the probabilistic routing protocol.

1.3.1 Flooding in Probabilistic Protocol

Mobile applications consist of heterogeneous nodes in terms of speed, energy, and buffer capacity. In addition, the mobility pattern (Leguay *et al.*, 2005) of each node varies. For example, a city bus as mobile node has a specific route and schedule to travel, cabs move randomly, pedestrians have variable timings to go on work places, visit marts and coffee shops, and so on. Due to these variations in mobility, all nodes have a distinct encountering rate with various destinations. For instance, a bus may be highly probable to meet a large number of destinations compared to pedestrians. Moreover, nodes may have different encountering values for the same destination. Consider that a train may have a high predictability value for a station compared to a bus or tram, meaning that a bus and tram have a lower encountering value for the same location. This leads to a problem in which the carrier continually forwards the message to highly probable contacts.

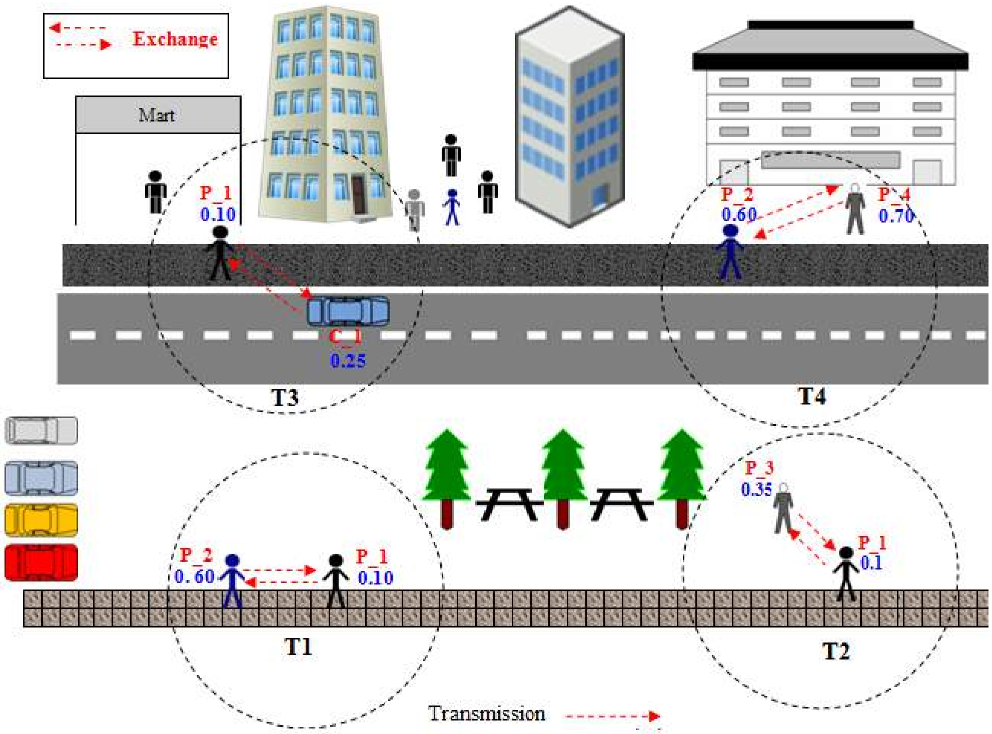

Figure 1.8: Message replication by probabilistic routing protocols

Consider a city based snapshot shown in Figure 1.8 consisting of a public park, main road and shops. The two types of mobile nodes such as pedestrians and cars have been considered. According to probabilistic protocol, P_1 forwards message M to P_2 at time T1 because probability value of P_1 (0.10) to encounter message destination is less than P_2 (0.60). The probabilistic protocol is Multi-Copy, therefore, message exists on P_1. The pedestrian P_1 again transmits message copy to P_3 (0.35) due to its high probability value at time T2. The pedestrian P_1 replicates message on car C_1 because probability value of car C_1 (0.25) is higher than pedestrian P_1 (0.10) at time T3. Meanwhile, P_2 (0.60) replicates message copy to P_4 (0.70) at time T4. These adaptive transmissions overflow buffer space and raise the message drop.

1.3.2 Dynamic Status of Network Node

In probabilistic routing protocol, each node itself computes its probability value by observing encountering rate with its known destinations. Furthermore, the node broadcasts its probability value to other nodes.

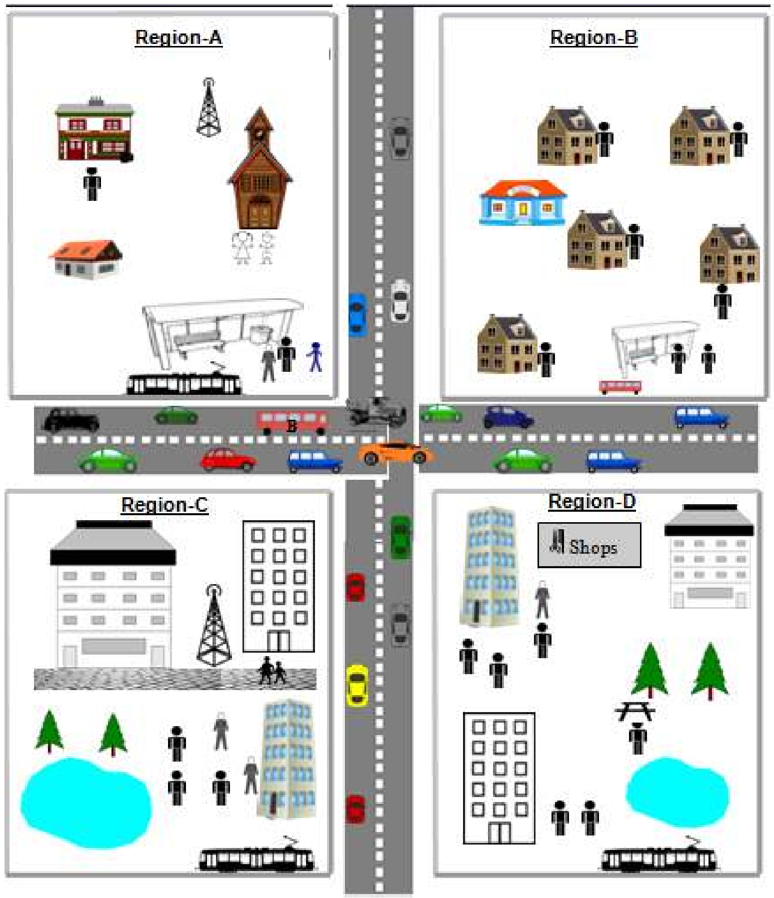

Figure 1.9: The transmission of messages on high probable nodes

The message is transmitted to a node only if it is highly probable to deliver it. This is not similar to Multi-Copy flooding routing protocols, in which a message is always replicated on encountering peers. However, in disrupted environments, network nodes dynamically change their status. This is due to the varying levels of network traffic and resource availability. As a result, it is impossible for a highly probable node to remain the best custodian for messages. In order to understand this problem, consider a city base environment shown in Figure 1.9 that is being divided into four Regions A, B, C, and D. Each Region consists of heterogeneous traffic mobile nodes such as pedestrians, bus, trains, cars, and cabs. The Region nodes have their own mobility pattern, speed, buffer sizes, and energy. The Regions are interconnected via buses, and each bus has predefined pattern and scheduled to move around Regions. The messages for dispersed Regions can be transmitted via store, carry and forward paradigm. Clearly, node interconnecting Regions, where city buses or trains, move on predefined path and on each day encounter with on-way locations multiple times.

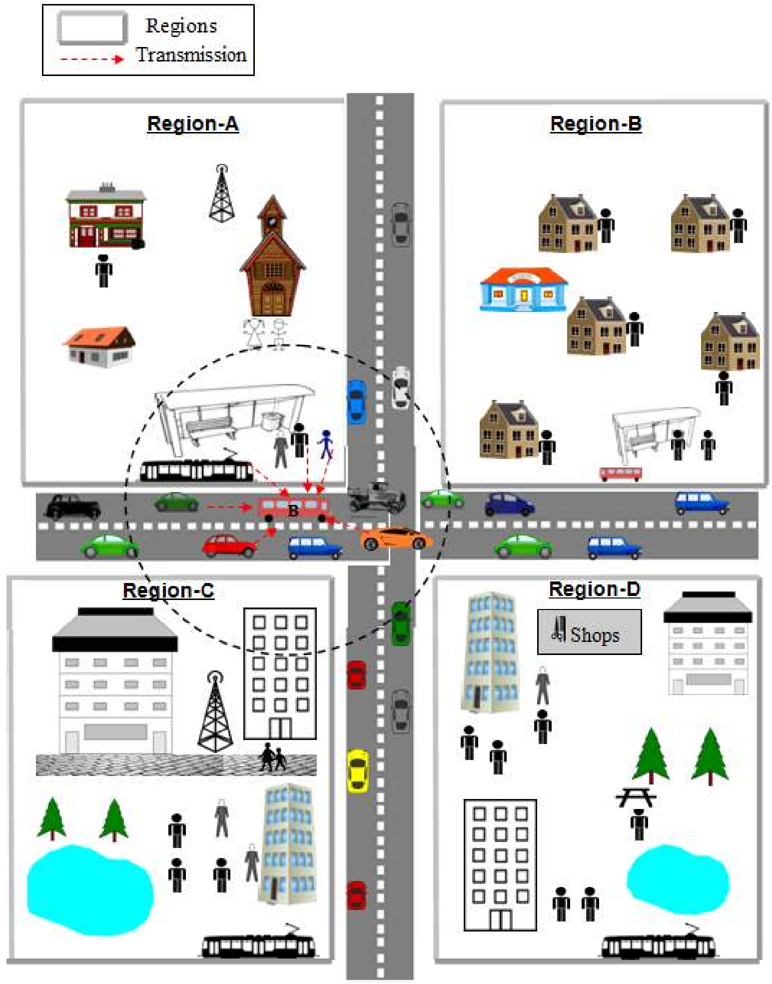

Figure 1.10: The transmission of messages on high probable nodes

In this way, these nodes hold high encountering value with a large number of destinations located outside and within Regions. According to probabilistic theory, a high encountering rate leads to high probability value. Therefore, trains and buses become eligible to receive large number of messages for dispersed locations. These nodes increase network throughput by delivering them to their destinations. However, the node mobility is unpredictable and a traffic jam may cause a delay and node must queue messages in a buffer. Meanwhile, it continues to receive the message from multiple sources due to its better probability value to meet various destinations. Since the buffer is finite, it dropped previously stored messages. This scenario is shown in Figure 1.10, in which bus B has been receiving the message from its neighbors. Hence, despite having high probability, bus B is no longer useful because it drops messages before delivering them to their destinations. Therefore, more network parameters are required to compute the present ability of a node to carry a message.

1.3.3 Message Destination and Hops

Probability computation based on encountering rate can forward message to a highly probable multi-hop away carrier. The multi-hops are the number of intermediate nodes between source and destination. Consider a city bus that travels on predefined route and holds high probability value for on-way buildings, shops, and plazas. This makes it more eligible to store and carry the messages for on-way destinations even though it may be many hops away. The multi-hop away node can drop the message before it is delivered. This is due to flooding of message from on-way nodes. Consider a scenario shown in Figure 1.11, where pedestrian P_1 (0.12) has forward message M to highly probable node bus B_1 (0.80) at time T1. The bus B_1 is not in direct contact and with a present movement pattern it is multi-hops away from the message destination. The multi-hop away node can drop the message before it is delivered. This is due to flooding of network traffic from on-way locations. Meanwhile, pedestrian P_1 (0.12) has replicated message to pedestrian P_2 (0.25) at time T2. Hence, even with lower probably value compared to bus B_1 (0.80), pedestrian P_2 (0.25) is a better carrier. The reason is that it is single hop away and is moving towards the message destination. Hereby, a method is required to compute the numbers of hops a message has moved away from its known destinations.

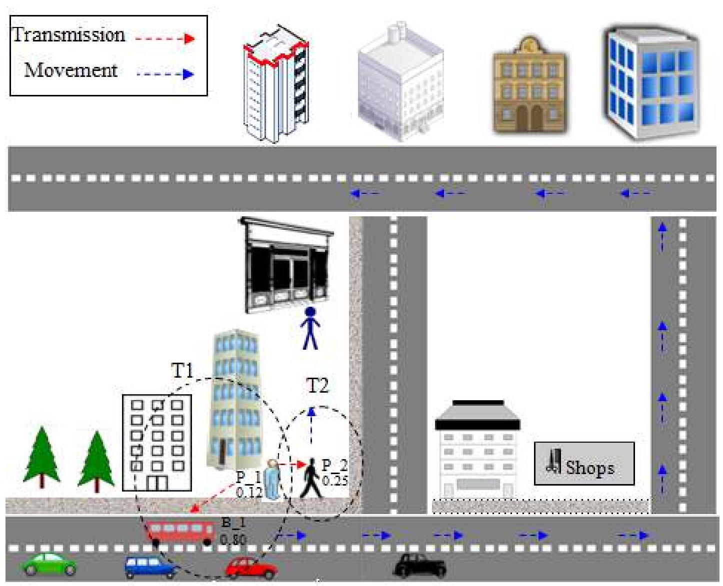

Figure 1.11: The destine node is multi-hop away

1.3.4 Message Drop and Protocol Efficiency

The existing DTN probabilistic routing protocol always replicates the message at a node with the highest probability value. The probabilistic routing protocol does not consider additional network parameters, such as buffer occupancy level at the receiver before message transmission. As nodes are equipped with finite buffer capacity, they cannot accommodate all incoming messages and may drop previously stored messages. The message drop effects delivery rate because the node was carrying messages due to its better probability value to encounter their destinations. Furthermore, the same highly probable node receives the dropped message from other parts of network and causes a loop of re-transmission and dropping.

Consider the snapshot shown in Figure 1.12, in which B_1 has received a message M from C_1 of size 450KB. At present, B_1 is full and must drop its previously stored messages to accommodate M. Hence, according to first come first serve (FCFS), B_1 has dropped M1 and M2. These drop of messages reduced delivery ratio because B_1 was carrying dropped messages due to its better predictability value to meet their destinations. The drop event cannot be removed completely, however, minimizing its impact can improve network throughput.

Node	Probability
X	0.54
Z	0.87
Q	0.45
S	0.90

Message	Size	DEST
M1	200KB	S
M2	320KB	Z
M3	400KB	X
M4	180KB	Q

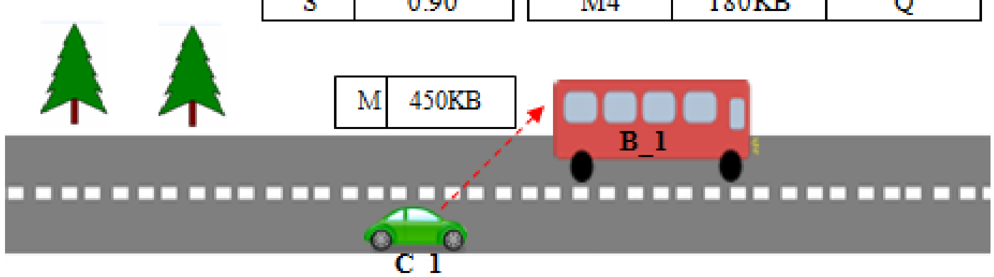

Figure 1.12: Limited buffer space drop previously stored messages

1.4 Research Statement

This thesis is aiming to minimize the resource consumption of DTN routing protocols by proposing Self Adaptive Routing Protocols in infrastructure-less city based environments. Self Adaptive term means that nodes change their transmission behavior according to resource availability.

The following are the research questions:

i. How to compute the current status of node, in terms of its present ability to carry the message?
ii. How to determine the position of node in terms of number of hops it has moved away from its known destinations?
iii. How to design adaptive routing protocols in which message transmission jointly observes probability value and available buffer space at the receiver before message transmission?
iv. How to fully utilize high probable nodes to deliver messages to their destinations and control number of message transmissions?

1.5 Research Aim

The aim of this study is to provide Self Adaptive Resource Aware Routing Protocols for city based environments in which message transmission decisions are adaptive and depend on available buffer space as well as current Quality Value of node. The quality of a node is determined in context of its current ability to carry a message. Each node itself maintains its self-status based on the number of messages transmitted, dropped, received, and delivered.

1.6 Objective of Study

The following objectives have been addressed to design and develop Self Adaptive Resource Aware Routing Protocols for DTN:

i. To compute current status value of node in terms of its ability to carry a message based on number of messages transmitted, received, dropped and delivered over an encountering interval.

ii. To determine the position of node in terms of number of hops it has moved away from its known destinations.

iii. To design the adaptive routing protocols for DTN those jointly consider probability value and available buffer space at receiver before message transmission.

iv. To fully utilize high probable nodes to deliver messages to their destinations and control number of message transmissions.

1.7 Scope of Study

The scope of this research covers the following issues:

i. This study focuses on data forwarding in city based environments in which disruptions are frequent due to mobility of nodes, buffer space is insufficient, and connections are opportunistic.

ii. The connection between mobile nodes is opportunistic, meaning that nodes do not have prior knowledge about time and duration of future connectivity.

iii. The mobile nodes are heterogeneous consisting of city buses, trains, pedestrians, cars and cabs. Each node has different energy, processing power, movement patterns, and buffer capacity levels.

iv. The network is self-configured and there is no centralized administration to control communication. Moreover, nodes can join and leave the network any time.

v. Each node will act as a node, meaning that it can generate source messages and also receive transmissions from other opportunistic available connections.

vi. The performance of proposed and existing routing protocols have been analyzed by using real time traces such as Helsinki city based environment, Haggle-Infocom and Sassy st.harvard university.

1.8 Outline of Thesis

The remaining thesis has been structured as follows: Chapter 2 contains an extensive literature review about Single and Multi-Copy DTN routing protocols. Chapter 3 depicts Research Methodology with an operational framework. Chapter 4 presents a Contact Quality Based Routing Protocol. Chapter 5 covers Buffer Aware Routing Protocols, while Chapter 6 discusses Threshold Based Locking. Chapter 7 is about Forwarding Impact Aware Protocol, and Chapter 8 presents the Conclusion.

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