Energy-aware Real-Time Route Prediction Framework for Embedded Systems

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Approval

It is certified that the contents and form of the thesis entitled "**Energy-aware Real-Time Route Prediction Framework for Embedded Systems**" submitted by **Ayesha Zahir** have been found satisfactory for the requirement of the degree.

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Abstract

Internet of Things (IOT) is becoming an important part of our lives as it integrates computing devices embedded in everyday objects and Vehicle of Things is a major part of IOT. This research is focused on traffic-aware optimal route prediction via ad hoc vehicular communication for developing countries like Pakistan where no specialized road side infrastructures and sensors are available. Vehicular ad hoc network (VANET) is created via Wi-Fi direct using smart phones which overcomes the requirements of special road side traffic gathering information sensors and cellular data based internet cloud, as used in developed countries like US, China, Japan. Offline maps data-set was generated for Islamabad Capital Territory and different route prediction algorithms are implemented to avoid congestion and can easily be executed over embedded devices. Results of our framework are based on average travel time and cpu, memory usage.

Dedication

This thesis is dedicated to the most worthy and valuable people of my life, my Parents, who gave me the strength to accomplish any task.

Certificate of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics which has been acknowledged.

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All thanks to Allah Almighty for His countless Blessings. Indeed this research was only possible with His help. Great thanks to mom and dad who stood for me in every phase of my life and give me strength.

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Lastly I would like to thank my beloved sweet sisters for their encouragement, support and love.

List of Abbreviations

Abbreviations

ACO	Ant Colony Optimization
API	Application Programming Interface
CI	Congestion Index
GPS	Global Positioning System
IoT	Internet of Things
IoV	Internet of Vehicles
ITS	Intelligent Transportation System
IEEE	Institute of Electrical and Electronics Engineers
MANET	Mobile Ad-hoc Network
MCS	Mobile Crowd Sensing
MD	Modified Dijkstra
OBU	On-Board Unit
PTA	Pakistan Telecommunication Authority

RSS Road Side Sink

RSI Road Side Infrastructure

RSU Road Side Unit

SVANET Smart Vehicular Ad hoc NETwork

SMaRTDRIVE Systematic Management of Road Traffic through Data Retrieval In VANET Environment

UCS Uniform Cost Search

V2I Vehicle-to-Infrastructure

V2V Vehicle-to-Vehicle

VANET Vehicular Ad hoc NETwork

WHO World Health Organization

WSN Wireless Sensor Network

WAP Wireless Access Point

WMN Wireless Mesh Network

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Chapter 1

Introduction

With the advancement in technology, Internet of Things is an emerging field which integrates embedded objects [16]. Internet of Vehicles (IOV) is a major part of Internet of Things (IOT) which forms a basis for Intelligent Transportation System (ITS). These Intelligent Transportation System are deployed for efficient road utilization to avoid road side injuries, traffic accidents, congested routes. For Intelligent Transportation Systems various methods are used and Vehicular Ad Hoc Network (VANET) is one of them. In our research we have used VANET for dynamic route prediction.. VANET is formed by making a vehicular network via road side infrastructures(RSI), vehicular sensors etc.

1.1 Wireless Ad hoc Networks

Wireless networks provides alternates to the costly networks that required connectivity through cables to connect multiple objects. These wireless ad hoc networks are used where we do not have to depend on infrastructure and the nodes can communicate with each other while moving along their path [22]. Simple wireless networks requires some Wireless Access Point (WAP) or some static station but wireless ad hoc networks do not require any access points because the network is built dynamically and automatically. However the communication in ad hoc network depends on how many vehicles are there and the distance between the vehicles in a network. [1]

Mobile Ad hoc NETwork (MANET) is an ad hoc network that requires a network of connected mobiles which forms a temporary network [22]. MANETs require special routing protocols which can handle the dynamically changing network in order to find routes from a given source to destination and main types of routing protocols are reactive and proactive and the third type is hybrid [3]. As the nodes are moving so it becomes error prone and if the nodes in a network are very less like two or three and they are moving close to eachother then no specific protocols will be needed for routing and to send data from one node to the other in a network. MANETs are independent of infrastructure [18]. In other case nodes in a network communicate to find the route from origin to destination and requires a lot of mobile computation thus consuming mobile resources [19].

Wireless Sensor Network(WSN) is another wireless ad hoc network. WSN forms a network of wireless sensors. These sensors can be in any device or vehicle and are used to detect any change in an environment or for security purposes to detect any activity. These sensor equipped devices can be implemented in an ad hoc network for monitoring and is capable of short range communication [20]. Wireless sensors usually have very limited energy, to

[1] http://www.idc-online.com/technical$_references/pdfs/data_communications/Ad_HocNetwork.pdf$

save its energy and computation there is a way in which the next node being selected should be based on some metric like link cost on which the information is sent to that node [29].

Wireless Mesh Network (WMN) is a network of mesh nodes. It is a form of wireless ad hoc networks with less mobility and forms a centralized approach providing more reliability. Mesh can be any device like mobile or laptops in this network. WMN's provides a hierarchical structure with two main part: mesh backbone and mesh client. Mesh backbone is a static mesh router connected to other wireless devices providing high bandwidth internet connectivity and mesh client can be anything like mobile phone or a laptop connected to a mesh backbone [27].

1.2 VANETs

VANETs are wireless networks with constant change and the nodes are in motion. Every nodes in this wireless network is a moving vehicles which forms a dynamic network arbitrarily. Each node in a network works as a router thus finding routes and sending information to nearby nodes in a network. VANET is a distributed approach in which vehicles form a network by moving in a routing graph with limited freedom in routes because the vehicles can only move on predefined routes in a routing graph [18].

Among the different types of networks and VANET is the most suitable for finding routes in a dynamic network. As the vehicles are moving continuously thus changing network dynamically so VANETs are self-organizing and self-configuring [22]. VANETs are formed by using Mobile Ad hoc Network(MANET) protocols but MANETs are not compatible with VANET because MANET cannot cope with the dynamic vehicular ad hoc network which is continuously changing.

VANETS provide ease, convenience and travel efficiency for straphanger and drivers [13]. It reduces the travel time and delays due to congestion and helps in avoiding accidents. VANET network can be formed via wireless connectivity or cellular data [18].

In VANET, vehicles communicate which helps them to have a safe, collision free and cooperative driving. But the connected is spontaneous and network often gets disconnected due to movement of vehicles in different directions, in order to keep track of vehicles GPS can be used [11]. VANET forms a vehicular network and is responsible for vehicular communication but it also facilitates data transmission between vehicles and other objects like road side infrastructures [15].

Vehicular communication can be from vehicle to other nearby vehicles (V2V), Vehicle to road side infrastructures (V2I). In ad hoc networks, nodes are moving and communicating with each other. In VANETs these nodes are the moving vehicles. However ad hoc network nodes communicates in two way, Single-Hop communication and Multi-Hop communication. Single Hop allows moving nodes to share information directly with each other but Multi-Hop requires relays or intermediate nodes for transferring information among the moving nodes. As the nodes are moving and communication from one node to another is done by passing through intermediate nodes so it requires high performance protocols for routing which will allow network changes [2] .

VANETs also support cloud services which saves computation power by accessing cloud resources and thus reducing cost [5]. In vehicular networks because the connection is for short time and changes quickly so it self-configures itself [23].

According to [17] every vehicle in vehicular ad hoc network sends and receive information with other vehicles and the communication range of VANET can be upto three hundred meters.

1.3 RouteNet

Route prediction based on congestion or shortest path is a data-driven approach. In many countries data is collected from traffic monitoring cameras which forms imagery dataset [12], radar and sonar sensors, induction loops which detects the type of vehicles ranging from small to large vehicles and counts the number of vehicles thus informing traffic density and flow of vehicles on a road [2].

With the rapid growth in metropolitan areas [1] in Pakistan there has been a drastic increase in the number of vehicles, with no traffic management strategies and transportation safety due to the lack of infrastructures like road side cameras or road side units for broadcasting and collection traffic information,or specialized vehicular on-board sensors. According to a survey by Texas Transportation Institute in United States, travelers usually spend

[2] https://books.google.com.pk/books?hl=enlr=id=k-zRBQAAQBAJoi=fndpg=PP1dq=wireless+mesh+ad+hc

48 hours a year stuck in traffic due to congestion and thus causing a wastage of 3 billion gallons of fuel in every year [2]. According to World Health Organization [3] there is a death toll of 1.3 million because of road accidents and approximately 20 to 50 million people suffer from road side injuries.

We have designed a VANET based framework for routing called **RouteNet**. Our solution is a decentralized approach forming a network of vehicles dynamically and locally for that area. Thus this network keeps on changing depending upon the number of vehicles in its network. Vehicles in this network share information to have a collision free and cooperative driving experience, avoiding congestion and accidental scenarios. Our RouteNet VANET framework is based on Reactive on-demand VANET protocol in which a source vehicle initiates a broadcasting message for route information to nearby vehicles in its network.

Our framework is designed for developing countries like Pakistan which is feasible enough to be used by majority of our population, and caters the absence of road side infrastructures, vehicular on-board units and unavailability of cellular data. Previously there's no framework for route guidance, this greatly increases road accidents and congestion. Our framework called RouteNet is also data driven but since there's no data available in Pakistan thus we have generated data for Islamabad and is stored in SQLite. This RouteNet is based on some algorithms which finds the traffic-aware shortest path because it decreases congestion, instead of finding shortest path from source to destination. This RouteNet will also be of great help for first responder vehicles to reach the incident location on time by avoiding congested

[3] http://www.who.int/violence$_{i}njury_{p}revention/road_{s}afety_{s}tatus/report/en/$

routes.

A* and Dijkstra are considered very good in finding shortest paths from source to destination but if the heuristic function in A* reaches zero then A* behaves like Dijkstra, in addition to this if the graph grows A* will not work optimally [8]. These two algorithms are static. For dynamic cost there's a need to implement alternate route planning algorithms for dynamic route planning.

So our framework RouteNet, makes a vehicular ad hoc network (VANET) via Wi-Fi Direct which is available in every smart phone. This framework is intended for android users. After connectivity to nearby vehicles it sends and receive traffic congestion information. Based on this information multiple algorithms are implemented for route prediction with Congestion Index (CI) as decision parameter [14].

In our proposed approach we have calculated Congestion Index using Speed Average Method. Unfortunately for developing countries like Pakistan, no traffic data is available and not everyone have live access to online maps for traffic information, so offline maps are generated for Islamabad city by traveling at different hours including rush hours and normal hours. Data is pre-processed and is stored in SQLite. Besides according to Pakistan Telecommunication Authority(PTA) [4] there are only 26.31% 3G/4G subscribers up till 2018 thus majority of our population do not have cellular data availability. So for the generated maps data, Uniform Cost Search, A* routing algorithm and modified dynamic Dijkstra algorithms are implemented

[4] http://pta.gov.pk/en/telecom-indicators

and compared with static classical Dijkstra algorithm for route prediction based on congestion information.

1.4 Background

Intelligent Transportation Systems are used for efficient road utilization and route prediction in developed countries that uses specialized sensors and cellular data for cloud storage to form a network. Data sets are also publicly available for further processing. Scenario of under developed countries like Pakistan, India, Bangladesh is different, because of lack of vehicular on-board units, road side units and cellular data availability.

Due to the lack of such specialized sensors and infrastructures which forms the basis of Intelligent Transportation Systems, there has been no framework for efficient road exploitation in Pakistan. This results in traffic congestion leading to economic loss and causing environmental pollution. It increases traffic accidents and road side injuries. Congestion can cause traffic delays especially for emergency vehicles to reach their destinations on time and that is the Golden hour in saving a person's life.

To avoid congested routes, VANET based framework provides alternate routes based on congestion index relayed from nearby vehicles in a vehicular network. This will help to avoid congested routes thus reducing travel delays especially at peak rush hours and thus reducing environmental and economic loss.

1.5 Problem Statement

We have observed in different developing countries like Pakistan, that there has been a big issue of long traffic delays due to congestion. Cellular data is not available to everyone which forbids them to have live maps access and besides that no traffic data is available for further processing. Vehicles do not have an in-built on-board units, as it only depends upon the owners choice if they want it or not. In Pakistan there has been no framework for route prediction and congestion avoidance.

1.6 Thesis Outline

Chapter 2 discusses about the advancements and developments in other countries for route prediction and congestion avoidance for efficient road utilization.

Chapter 3 discusses the proposed method of implementing VANETs and how route prediction is done using multiple algorithms for offline maps data, for Islamabad capital territory and contains all the technical details of our proposed approach. It also discusses resukts of our framework and consists of the comparison between our implemented algorithms and their performance regarding CPU, memory and network usage.

Chapter 4 concludes all the research work done and discusses different aspects of future work which can be done to further enhance the routing problem for an under developed country scenario.

Chapter 2

Literature Review

Transportation plays an important part in a country's economy, that's why mostly countries are paying more attention in making their transportation systems better by making intelligent systems that confronts congestion and reduces traffic delays. Traffic data is continuously being collected and monitored and critical information is communicated to nearby vehicles via Road Side Units(RSU) and cloud servers. This helps to avert congested routes and thus reducing environmental and economic loss.

In [8] authors have implemented nature inspired Ant Colony Optimization(ACO) in order to find the shortest best path in a routing graph. They have developed this algorithm for the changing cost of routes based on congestion. Thus in order to observe the dynamic link costs they have used link travel time. ACO is based on pheromones which is used by ants to notify others ants regarding the food source. Ants path is depicted as routes in a distributed graph. ACO usually provides a centralized approach which assumes that all the information is visible locally to a particular device but in this paper they have modified ACO for a distributed environment. Traffic network is unidirectional in this routing graph. Link travel time is used with ACO which computes the travel time of a vehicles or virtual ant in a graph. This travel time varies for each link in a network. This algorithms start from the source node from where ants start their food finding journey and on their way to food search they will keep on updating their pheromones. In order to make it more effective they have proposed a trade off between exploration and exploitation. If ants do more exploration they will forget about their predecessors information about a path, so they must focus on exploitation which will help increase pheromone. This pheromone is used as a heuristic which informs other virtual ants to explore more in a particular route thus finding more variants of that solution. More the pheromones more will be unique solutions.

In [7] authors have proposed a system for emergency vehicles to reach incident location on time. Their approach involves Road Side Units (RSU) that collects traffic information from vehicles. Every vehicle in this scenario has an embedded Global Positioning System (GPS) system and has a special On-Board Units(OBU) which exchanges broadcast emergency messages from Road Side Units. To reduce the travel time by predicting better and faster routes authors have used Dijkstra algorithm.

In [21] authors have proposed a smart vanet base data routing protocol. This approach is intended for vehicles in highway. Their proposed protocol uses leader algorithm for exchange of messages between nearby vehicles. This protocol involves several road side units for transferring traffic information to nearby vehicles and to other RSU's. Multiple Road Side Sinks (RSS) are present to transfer data from one RSU to another acting as a multi-hop.

This data transmission is done using IEEE wireless protocols. Each vehicle is equipped with a specialized Zig-Bee sensor located at the front of each vehicle which detects congestion and any accidental scenario or icy roads and transmits data to vehicular on-board units(OBU) in a vehicle through cable. These OBU sends traffic information to the vehicles in this smart vehicular ad hoc network. In this way nearby and far away vehicles are alerted about the situation ahead and helps them avoid congestion or accidental situation by taking alternate exits on highways.

In [26] authors have proposed a system that sends and receive data from vehicular on-boards units and sensors to cloud servers where traffic data is collected and monitored. This data consisting of vehicle speed, location and direction is used to make a weighted matrix for routes between stations thus creating a weighted and directed traffic network. Dijkstra algorithm based on min-priority, is then used on this weighted matrix to predict optimal route in order to avoid congestion and is tested between two stations in China.

In [24] authors have implemented VANET based framework for emergency vehicles to avoid congestion. It works on android app named SMaRTDRIVE. Each vehicle has an on-board unit and sensors that collects traffic data and send it to SMaRTDRIVE via Bluetooth. This application then forwards this data to servers using cellular data, where this information is further processed and emergency vehicles are alerted by sending user location, in case of any emergency. This on-board unit also sends data to nearby vehicles via Wi-Fi Direct and to Road Side Units, thus broadcasting traffic information to alert drivers about congested routes ahead.

In [28] authors have developed a navigation system based on route prediction algorithms which avoids obstacles and objects from disastrous situations like flood, fire or any man made hazardous situation. For route guidance multiple algorithms are used which includes auction algorithm, A* algorithm and uses insertion heuristics for different path planning scenarios like one-to-one, many-to-many, one-to-many.

In [12] authors have developed a framework for vehicle routing. They have developed a data-driven method called En Route consisting of multiple components. As their approach is data driven so they have gathered data from traffic monitoring cameras, taxi cabs and from highways, in London. This framework evaluates traffic flow, compactness, routing and source-destination matrix. Their work is focused on traffic aware routing instead of finding only the shortest path, thus reducing traffic congestion and is based on pre-processed images data set. Origin-Destination matrix is formed which represents the number of vehicles, this is computed using induction loops which are placed under the roads and tally the number of vehicles passing over it.

In [25] authors have proposed a framework that helps vehicles to avoid congestion thus reducing environmental pollution like sound and air. For congestion avoidance they have used Yen's algorithm in accordance with Dijkstra algorithm on open data-set. Their cost parameters are road segment length and congestion on road.

These approaches provides route guidance by means of RSU, on-board units, cloud servers and sensors, thus making Intelligent Transportation System(ITS). Since in our country Pakistan, we do not have specialized vehicular sensors, on-board units and road side units/sinks, so we have developed a route guidance framework that is feasible for our scenario.

Our framework RouteNet will helps in averting congestion and allowing especially emergency vehicles to take best routes based on congestion. In Pakistan traffic data is not available publicly so we have generated offline maps data-set for Islamabad capital territory incorporating users to have route prediction without the need to access live maps.

In next section we have discussed our proposed RouteNet framework in detail and shows the results of our implementation work. We have also provided the comparison of using different algorithms for route guidance based on congestion.

Chapter 3

Proposed Method

For efficient road utilization and congestion avoidance, we have developed a VANET based RouteNet framework which provides real time dynamic route prediction. Routes were generated from National University of Sciences and Technology to Islamabad Interchange. User has to download the offline map(tiles) and in order to reduce memory consumption user can download offline maps of any specific area only. RouteNet provides a **Visualization Module** which displays all the necessary information to user including maps, user current location, shortest route based on congestion. This module automatically picks user's starting point and user can just enter the destination. Initially all the routes are shown from source to destination and a blue color polyline route is drawn from source to destination representing the shortest route based on static parameters of Dijkstra algorithm as shown in Fig. 3.1 .

Fig. 3.1 is displaying all the paths from source to destination and blue color line is the shortest route based on Dijkstra. This is computed using distance as weights. Cost function for assigning weights in Dijkstra is in

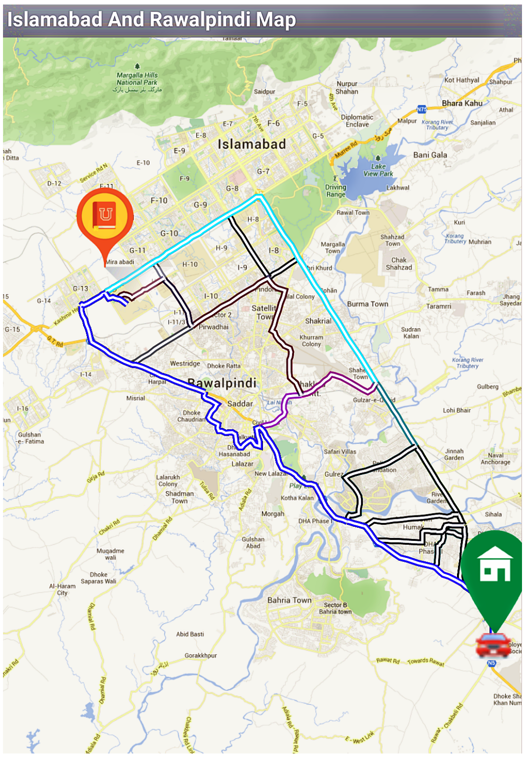


Figure 3.1: Dijkstra

eq.3.1

$$W_{rdSegment} = \frac{Len_{RS}}{V_{Max}} \tag{3.1}$$

RouteNet has another module called **Daemon Module** which runs in the background and is responsible for creating vehicular network. Thus RouteNet first builds a vehicular network by connecting nearby vehicles through Wi-Fi Direct. As Wi-Fi Direct is available in every android device and it does not cost anything to connect via Wi-Fi Direct so it is feasible to use. It sends and receives information from other vehicles and forwards this information to another module called **RouteNetKernel**.

On connectivity, this RouteNetKernel computes Congestion Index based on information received from other vehicles. Only vehicles in a network can relay congestion information to other nearby vehicles in that network. In this research we have used congestion as our cost function. Each road segment is assigned a weight based on it's length and speed of vehicles on this road segment. **Congestion Index (CI)** is computed for each road segment based on the information received from other vehicles. There are multiple ways to compute Congestion Index, we have used **Speed Average Method** for CI as in [4]. This CI takes actual vehicular speed and maximum speed allowed on that road segment to compute CI for each road segment in this routing graph. It is computed from the start of each road segment and is sent to nearby vehicles when the information is required.

The average velocity and cost of each road segment is calculated using Eq.3.2 and Eq.3.3 respectively.

$$V_{rdSegment} = \frac{\sum_{i=1}^{N} V_i}{V_N} \tag{3.2}$$

$$W_{rdSegment} = \frac{V_{rdSegment}}{V_{maxVel}} \tag{3.3}$$

Equation 3.2 finds the average of vehicle speed, this is done by adding the velocity of each vehicle on a particular road segment and Vn represents the total number of transports on a road segment. Equation 3.3 is used to compute the weights or cost of a road segment in a routing graph. Vmaxvel represents the maximum allowed speed of a vehicle for a road segment.

Dijkstra algorithm provides shortest route but since it has static parameters so it does not cater the changing cost of route based on congestion. In order to make Dijkstra algorithm to predict routes in Real-Time we must incorporate the changing cost with time for each road segment thus a modified version of Dijkstra algorithm is implemented as in [14]. So in place of static weights, we have used CI for dynamic prediction. On the basis of this CI, we have implemented a *Modified Dijkstra* algorithm which runs dynamically based on CI as computed in above equations. As each road selection decision is to be taken at junctions so this algorithm runs at road intersections, thus next road selection computation equals to the number of road junction from source to destination.

Fig. 3.2 shows the routing graph computed by Modified Dijkstra and Uniform Cost Search. Routes are computed at every intersection and both vehicles took shortest routes based on congestion. Both algorithms show results as in fig3.2 but differs in computation and average travel time.

In addition to greedy approach of Modified Dijkstra, we have implemented a best-first search variant called *Uniform Cost Search* algorithm [9] for single source single destination, which also uses CI as a cost function and computes next shortest route based on the cumulative cost from source till that road junction. Route selection is also done at each road junction using eq.3.2 and eq.3.3. UCS ensures that the cost of our path from source till some specific

Algorithm 3.1 Modified Dijkstra Algorithm – Dynamic recalculation shortest path

Input: Weighted graph and information from neighboring vehicles in VANET

Output: Updated shortest path based on congestion

```
for each neighbor u of v do
    for each vehicle in VANET do
        V_i ← Vehicle speed on road segment u
        N ← Total number of vehicles on road segment
        V_max ← Maximum velocity of vehicle on road segment u
    end for
    Calculate Congestion Index using Speed Average Method
    cost = CI + dist(u,v)
end for
for each u∈G do
    new − path = min.cost(u)
end for
selectedroute ← add new-path to selected track
```

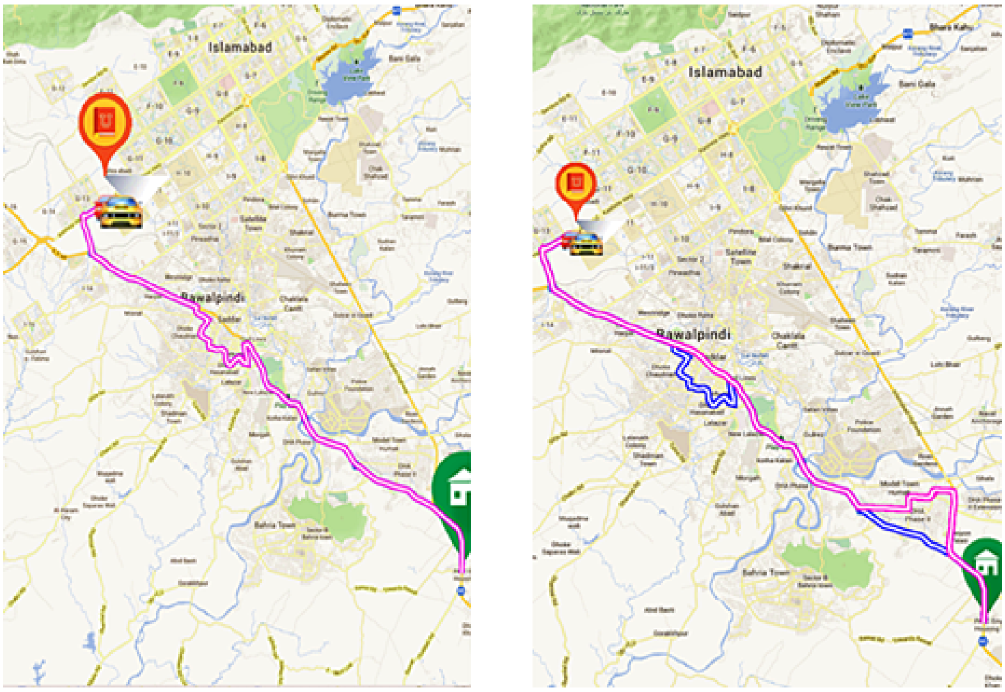


Figure 3.2: Routing Algorithm

point in a routing graph is the smallest. This computation is also Real-Time and dynamic as it incorporates the changing cost of each road segment on the basis of congestion information gathered from other vehicles as shown in Fig.3.2.

Modified Dijkstra and Uniform Cost Search provides traffic-aware shortest routes instead of showing shortest routes based on shortest distance only. Routing graph is a bidirectional graph, so there can be a scenario in which in order to find the shortest path it can direct vehicles to turn back thus making a vehicle to get stuck in a loop. In order to avoid such a scenario we have implemented in a way to make the graph unidirectional thus avoiding loops and by only moving forward in a routing graph.

3.1 Experiments

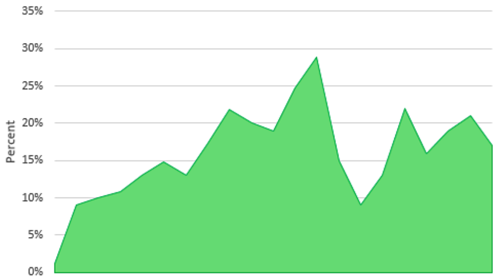
All the algorithms are implemented using Android Studio and are tested on Android devices with API levels 25 and 26. Uniform Cost Search and Modified Dijkstra both first creates a vehicular ad hoc network via Wi-Fi Direct. After exchange of traffic congestion information, computes CI and predicts routes based on congestion thus finding shortest routes to avoid congestion.

Fig.3.1 shows initial maps drawn from source to destination and shortest path drawn in blue color polyline based on classical Dijkstra algorithm. Fig.3.2 shows the emulation results of shortest path drawn using Modified Dijkstra and Uniform Cost Search algorithm.

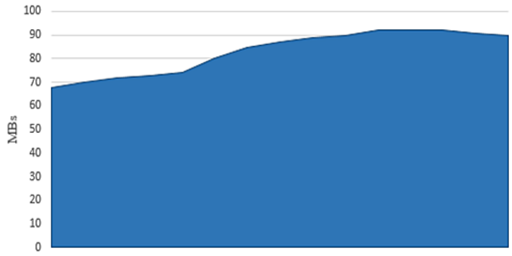
3.2 Results

Results are computed using Android Profiler on Android Studio. Our results are based on CPU usage, Memory consumption, Network speed and average travel time. The reason for selection of CPU, memory and network usage as an initial benchmark is to determine the most suitable algorithm for energy constraint devices, where limited memory and computing power is available.

Dijkstra is used as a baseline, as shown in fig 3.2 with a blue color route showing shortest path based on distance. At places where our proposed algorithms provide alternate routes other than Dijkstra, as shown in magenta color polyline, it elucidates that this is the shortest path based on congestion, this may increase distance but will also increase average speed and reduces average travel time.



(a) CPU Usage



(b) Memory Usage

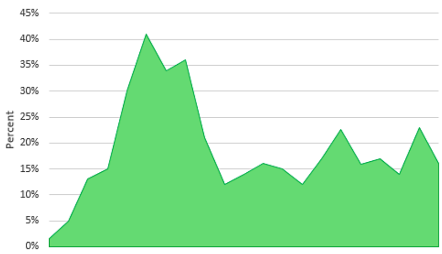
Figure 3.3: Dijkstra

Dijkstra algorithm uses approximately 30% CPU usage during execution. As Dijkstra algorithm do not forms a vehicular network so network speed is not computed.

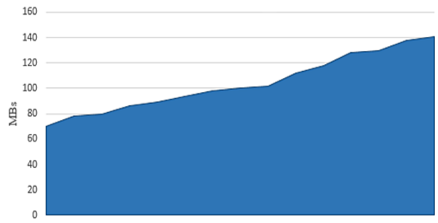
Whereas, Uniform Cost Search CPU usage is around 25% while occupying around 140 MB's of memory and data sent over the network is approximately at the rate of 231 B/s and receiving rate is 204 B/s depending upon the distance between devices.

Modified Dijkstra cpu usage is around 20% and memory consumption is almost 145 MB's. Network usage is approximately the same as Uniform Cost Search depending upon the distance between vehicles in a network. So network usage is around 206 B/s as receiving rate and 232 B/s as sending rate. Route selection is done at every junction.

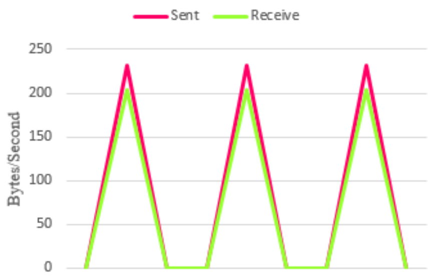
When this RouteNet starts CPU usage becomes greater because when it starts CPU has to draw an initial graph along with static Dijkstra algorithm route showing the initial shortest path from source point to destination. Along with this CPU starts computing Congestion Index based on information received and sent to nearby devices after vehicular network is formed.



(a) CPU Usage

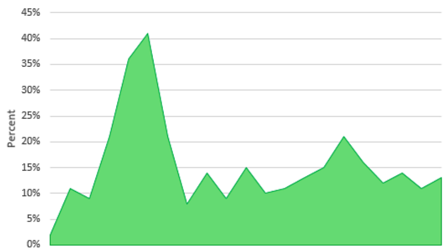


(b) Memory Usage

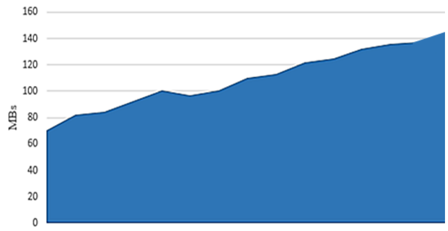


(c) Network Usage

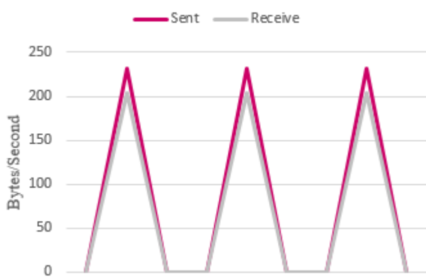
Figure 3.4: Uniform Cost Search



(a) CPU Usage



(b) Memory Usage



(c) Network Usage

Figure 3.5: Modified Dijkstra

Thus initially CPU usage is approximately 46%.
Results displaying shortest routes based on these algorithms are shown in the given figures. These are the individual performance of our algorithms.

3.3 Comparison

This section provides the comparison of performances of our implemented Modified Dijkstra and Uniform Cost Search with already implemented A* and simple Dijkstra algorithms. This comparison is done based on CPU usage, memory usage, network usage and average travel time. CPU, memory and network usages are considered as our performance metrics because mobile devices are resource constraint devices with limited space and power computation so these parameters needs to be considered regarding performance. Besides average travel time is calculated from 15 different observations for different source and destination points for A*, Modified Dijkstra and Uniform Cost Search as in fig 3.9. In our RouteNet framework all the implemented algorithms consumes approximately 2-3% device battery which is appropriate and each vehicle has an additional option to charge mobile devices so battery consumption is minimal.

Network usage of Uniform Cost Search and Modified Dijkstra are approximately the same and depends upon the distance between the vehicles.

VANET network is spontaneous and self-configuring, it changes dynamically. So the vehicular network is creating and changing continuously depending upon the vehicles nearby. This effects CPU computation and network

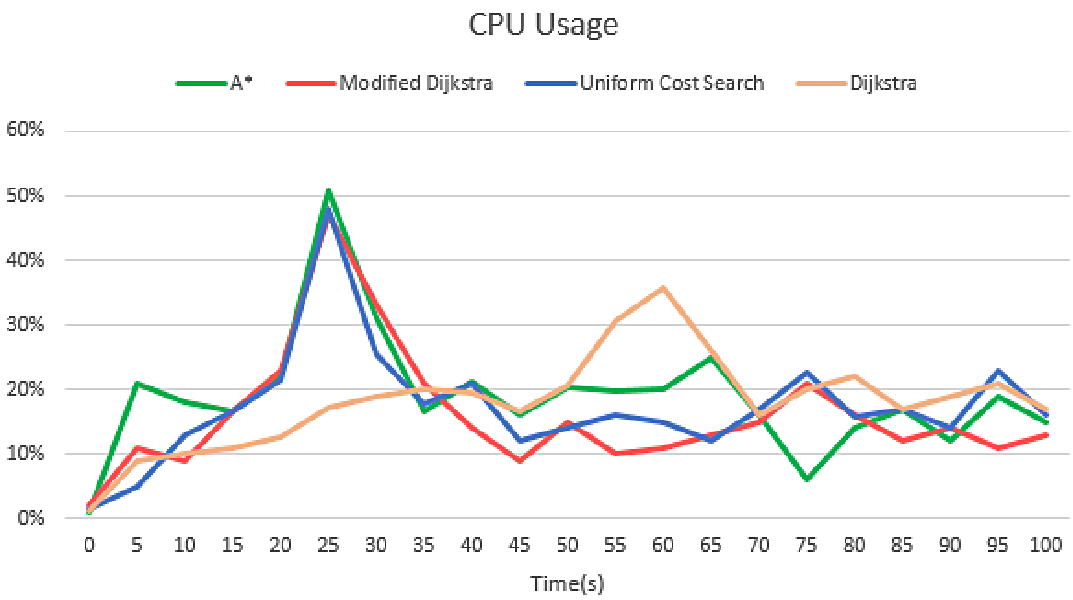


Figure 3.6: CPU Usage Comparison

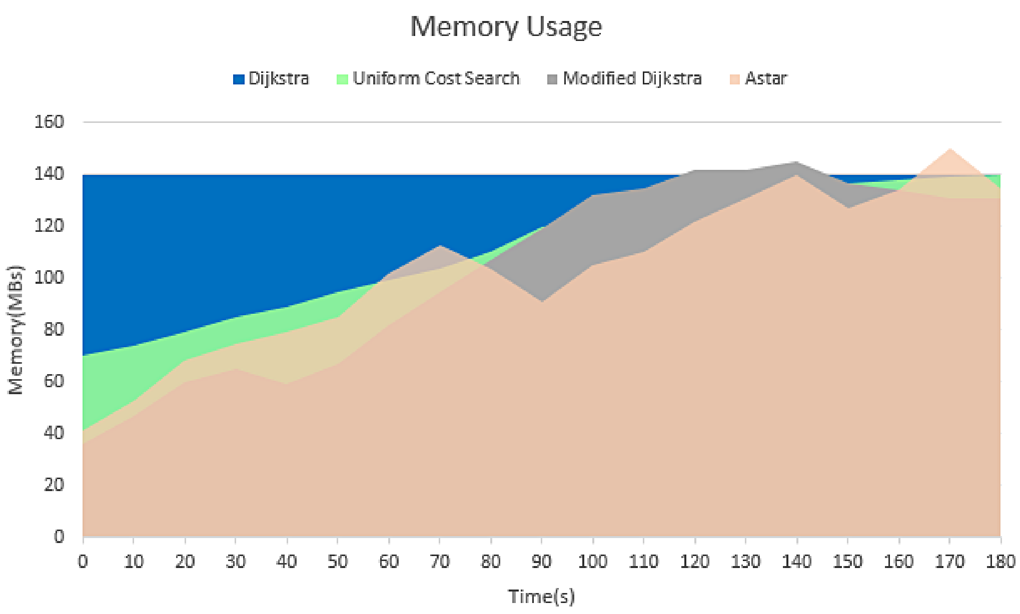


Figure 3.7: Memory Usage Comparison

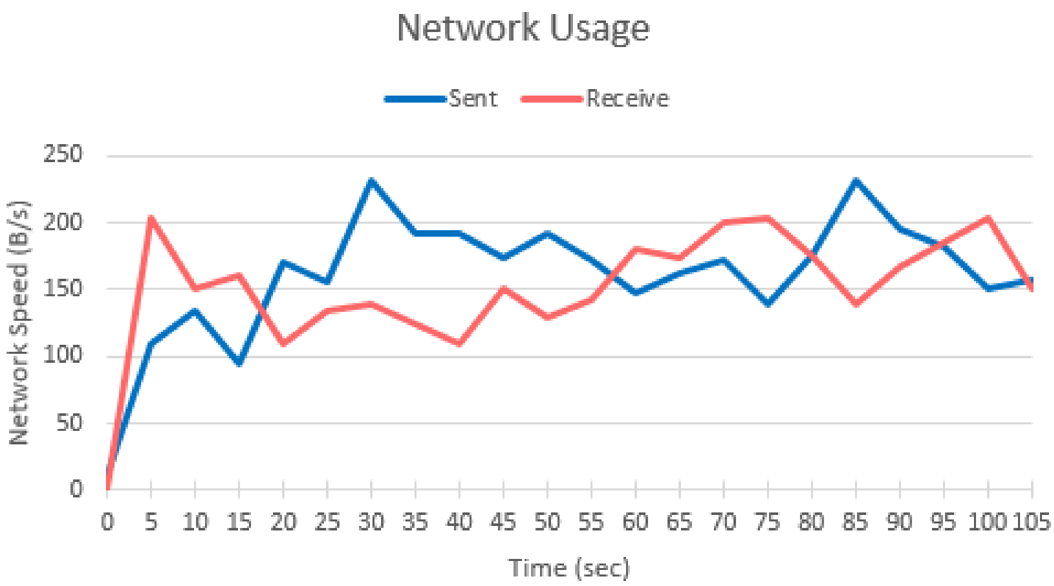


Figure 3.8: Network Usage Comparison

usage.

Fig 3.9 shows that our implemented Modified Dijkstra has the least average travel time thus readily improving static Dijkstra. UCS average travel time is greater because it provides the shortest route based on the cumulative cost and congestion index. Route provided by UCS might have the shortest cumulative cost with least congestion but it will increase the average travel distance thus increasing travel time. Our results of both algorithms which are UCS and Modified Dijkstra shows that they perform better than A* and Dijkstra algorithm.

With the growth in the number of vehicles there is an increase in CPU computation because more computation will be needed to send data to all the vehicles in a network and more computation is needed to store and pro-

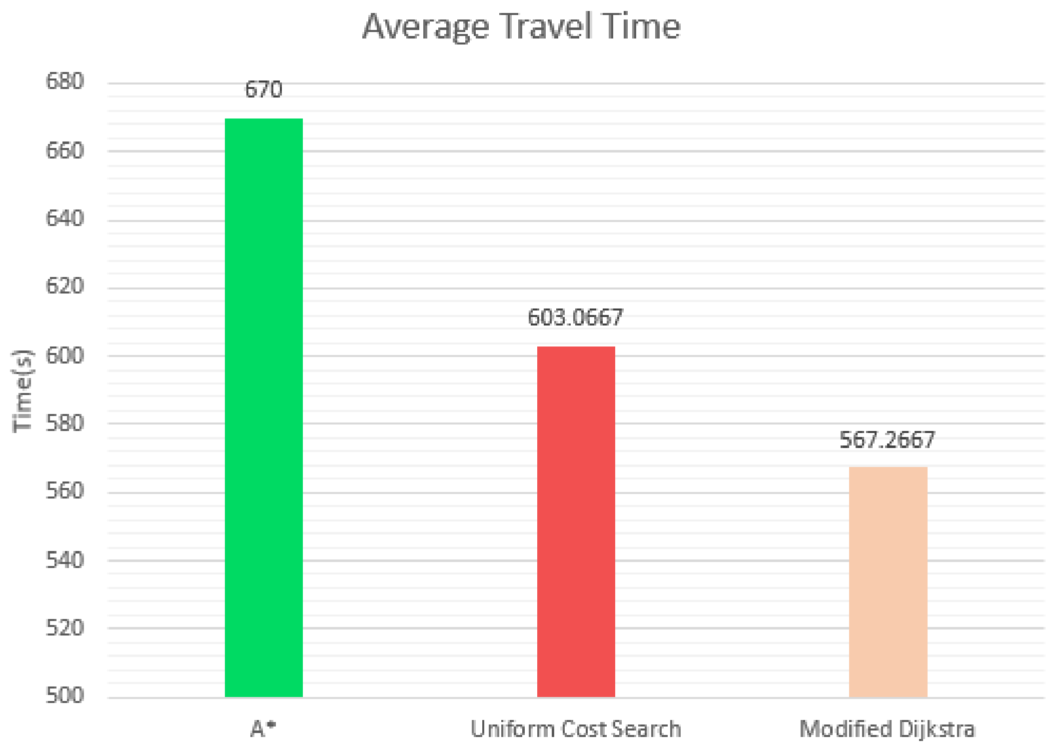


Figure 3.9: Average Travel Time of 15 Observations for Different Source and Destination Points

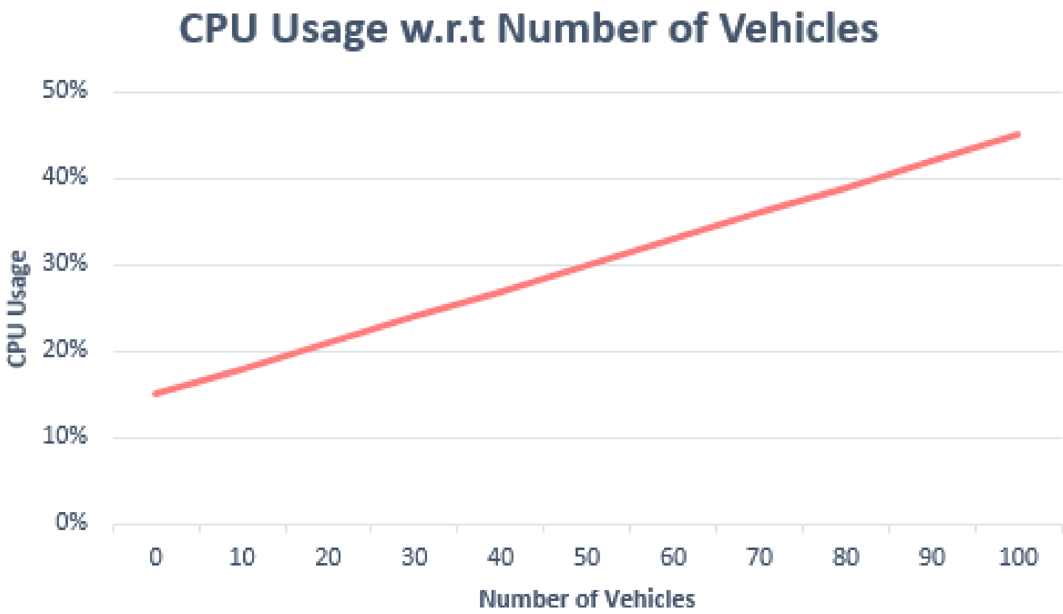


Figure 3.10: CPU Usage w.r.t Number of Vehicles

cess all the information received from nearby vehicles in a network. Network usage is also being affected. If the vehicles are nearby then network speed will be greater and if the vehicles are getting farther away then the network speed will also decrease.

However the algorithms implemented in this thesis requires limited computation and memory storage. To limit the CPU computation and memory storage we can limit the number of vehicles in vehicular network upto the extent to provide optimal results. Besides every vehicles has a facility to charge mobile phones which can save battery usage.

Chapter 4

Conclusion

This thesis has focused on traffic control issue in Pakistan due to rapid increase in the number of vehicles. There is no facility to improve our traffic management. Therefore we have presented a framework that will make driving safe and avoid traffic jams, collisions and thus reducing environmental pollution. This framework is based on vehicular ad hoc network which creates a dynamic vehicular network and allows vehicular communication. Although VANETs provides different forms of vehicular communication using vehicular on-board units, specialized sensors, road side units or infrastructures, cloud services. According to our results, Modified Dijkstra provides the shortest routes based on congestion with smallest average travel time as in fig 3.9.

As these smart sensors and services are not readily available in under developing country like Pakistan so our RouteNet framework helps in providing better driving experience by allowing vehicles to communicate with nearby vehicles via Wi-Fi Direct, sharing traffic information and overcomes the need of on-board units or road side infrastructures. Multiple algorithms are implemented to find the shortest path based on traffic, thus reducing congestion by avoiding congested paths in a routing graph. This helps users to have offline maps routing protocol without accessing live maps for route prediction or using cloud resources via cellular data.

Chapter 2 presented an overview of related work. It discusses how developed countries uses infrastructures and all the available facilities for efficient road utilization to make Intelligent Transportation Systems.

Chapter 3 discusses our proposed approach to make safe and cooperative driving with less travel delays. It will help avoid road side injuries and allow users to have access to the shortest route based on congestion. It also discusses the results of using different algorithms and provides comparison of using these different approaches.

4.1 Future Work

This thesis provides all the details regarding route guidance framework. It also discusses performance measures and comparisons. However it can be extended to provide more scalability. Data was generated for Islamabad in future it can be generated for more places with more performance measures to make it more robust. It can involve AI to enhance it's features.

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