國立交通大學

網路工程研究所

碩士論文

雙階層交通資訊網路中的適應性路由機制

An Adaptive Routing Algorithm for Two-Tier Traffic Information System

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中華民國　一百年六月

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摘要

近年來智慧型運輸系統的研究逐漸受到重視，而智慧型運輸系統中的重要服務之一為提供即時的交通資訊。為了降低即時交通資訊系統的建置成本以及提高系統可靠度，分散式的系統例如以車間隨意通訊網路(Vehicular Ad-Hoc Network)或是點對點網路(Peer-to-Peer Network)為主的交通資訊系統被提出。為了進一步改進交通資訊查詢的成功率以及降低查詢的延遲，近年來的研究提出雙階層交通資訊網路來整合車間隨意通訊網路以及點對點網路。 然而，由於交通資訊查詢被同時廣播到雙階層網路中而導致重複的查詢封包，進而產生額外不必要的系統流量及負擔。 本論文提出一個適用於雙階層交通資訊網路中的適應性路由機制以提升交通資訊查詢的效率。實驗結果顯示提出的適應性路由機制可在維持相同的系統查詢成功率之情況下，有效降低系統不必要的流量並同時降低交通資訊查詢的延遲。

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Abstract

Intelligent Transportation Systems (ITSs) have attracted much attention recently. One of the most important services for ITSs is to provide real-time traffic information service. To reduce the deployment cost and achieve high service availability, decentralized approaches such as VANET-based or P2P-based traffic information systems were proposed. To further improve the successful rate of traffic information lookups and lookup latencies, a new two-tier traffic information system which integrates low-tier VANET and high-tier P2P systems has been developed. However, conventional two-tier traffic information system may introduce extra routing overheads since the information lookups are broadcasted over two tier networks and introduce redundant lookup messages. This study proposes an adaptive routing mechanism in two-tier traffic information system to improve the efficiency of traffic information lookup. Simulation results demonstrate that the proposed scheme reduces the lookup latency and overhead while achieving the same lookup successful rates compared with the conventional approach.

Acknowledgment

這份論文能夠完成，首先必須感謝指導教授曹孝櫟博士的指導與幫助，在研究的過程中給予了許多珍貴的建議以及適時的指導，並讓我學習到做學術研究的方法與態度。同時，也非常感謝我的論文口試委員曾建超教授、鄭瑞光教授給予了許多針對論文的建議，有了口試委員們的寶貴建議使得這份論文更趨完善。

除此之外，我想感謝實驗室的學長以及學弟學妹，無論在學業、研究、或是學生生活上的幫助，讓我度過了一個充實的研究生活。最後，感謝每一位曾經關心或幫助我的朋友們，謝謝大家。

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1. Introduction

Intelligent Transportation Systems (ITSs) have been proposed for years to provide many advanced services for transportation system, such as car navigation, accident avoidance, traffic signal control, and parking information. Traffic information service is an important ITS service and it provides real-time traffic information for drivers and car navigation systems. With real-time traffic information, a navigation system could direct drivers to their destinations through the paths with the minimal traffic.

In order to support real-time traffic information service, the traditional solution utilizes on-road sensors to report traffic information. However, this solution imposes high installation costs and maintenance costs. In addition, reported information is limited to selected locations. If sensors are not installed on this road, there is no way to get the traffic information. Therefore, an alternative solution has been proposed to overcome the shortage of fixed sensors by collecting traffic information through vehicles.

While traffic information collections are performed by vehicles, dissemination mechanisms of traffic information become an important issue. Constructing a centralized server in Internet for information exchanges is a trivial solution, but it is not efficient due to the long delay of accessing Internet through cellular network (e.g., 3G). Moreover, traffic information systems constructed by a centralized server may suffer a single point of failure.

In contrast, exchanging traffic information directly between vehicles in a decentralized manner can avoid maintenance costs of centralized servers and also achieve reasonable lookup efficiency. For this reason, vehicle to vehicle communications (V2V) are needed to support traffic information collections and disseminations between vehicles. Currently, solutions of V2V communications can be categorized into two types: vehicular ad-hoc networks (VANETs) and peer-to-peer (P2P) over infrastructure networks.

In VANET-based V2V systems, several state-of-art VANET routing algorithms have been proposed to find paths for traffic information lookups. However, when the distance between the source and interested road segment increases, VAENT routing algorithms encounter the “too many hops” problem and then induce high delay. Moreover, since it is a highly dynamic topology in VANETs [1], frequent disconnections between links cannot be avoided; in other words, there may not exist any path from lookup initiators to destinations in the VANET. Those issues make most of VANET routing algorithms unfeasible for routing traffic information lookups.

On the other hand, infrastructure-based V2V systems provides almost “always on” network connections for vehicles. It takes the advantage of existing cellular network infrastructures, such as Universal Mobile Telecommunications System (UMTS) and High Speed Downlink Packet Access (HSDPA), to get the rid of the “frequent disconnections” problem. In infrastructure-based V2V systems, vehicles connect to Internet to construct P2P networks so that traffic information can be collected and distributed through vehicles.

Although infrastructure-based V2V systems provide better connectivity than VAENT-based V2V systems, the link latency is much higher. A series of practical experiments [2] demonstrates that UMTS link latency is at least 250 ms per hop, but VANET link latency is only 1 ms per hop. Apparently infrastructure-based V2V systems may seriously downgrade the performance of real-time traffic information service due to high latency.

Therefore, in order to take advantages from VANET-based and infrastructure-based V2V systems, a two-tier traffic information system, P2PNavi [3], has been proposed to route traffic lookups to both the VANET and the P2P network simultaneously. In P2PNavi, traffic lookups are able to reach destinations with low latency through the VANET, or reach destinations through the P2P network while lookups through the VANET are failed. As a result, two-tier traffic information system achieves both low latency and high success rate. Nevertheless, two-tier traffic information system introduces high routing overheads due to routing lookups to both tiers. This causes unnecessary P2P routing overheads while the VANET can efficiently deliver lookups to destinations. In addition, in the situation that the VANET is disconnected between the lookup initiator and destination, P2PNavi system always routes the lookup in the P2P network until the lookup reaches its destination. It means P2PNavi system does not consider that the lookup may be able to reach its destination through the VANET from one of intermediate P2P nodes in the P2P routing path. This results in not only losing the chance to deliver the lookup through the VANET with lower latency, but also wasting extra P2P network resources.

In this study, an adaptive routing algorithm is proposed to address those issues in the two-tier traffic information system. The adaptive routing algorithm achieves reasonable lookup success rate and lower latency, and reduces P2P routing overheads compared with P2PNavi.

The remainder of this thesis is organized as follows. Related works are discussed in chapter 2. In chapter 3, the concepts and the adaptive routing algorithm are proposed. Experiment results are presented in chapter 4. Finally chapter 5 concludes this thesis.

2. Related Work

In recent years, developing efficient mechanisms for V2V communications becomes an important issue. In general, network topologies for V2V communications can be categorized into three types: vehicular ad-hoc network, infrastructure network, and hybrid network.

The basic idea of ad-hoc networks is communicating without any fixed access points or base stations. All nodes in the network are self-configured, and communicate with each other by wireless interfaces. The research area of ad-hoc network includes mobile ad-hoc network (MANET), VANET, and others. Since VANET is a special case of MANET, applying MANET routing algorithms in V2V communications is possible. For example, ad hoc on demand distance vector (AODV) [4] and dynamic source routing (DSR) [5] are well-known MANET routing algorithms. AODV creates routes only on demand to reduce overheads. Greedy Perimeter Stateless Routing for Wireless Networks (GPSR) [6] makes greedy forwarding to delivery packets in open space.

However, due to the extremely dynamic topology changes and radio obstacles in road environments, traditional MANET routing algorithms do not achieve high performance while they are applied in V2V communications [7]. As a result, many routing algorithms which consider VANET characteristics have been proposed within the past years. In general, VANET routing algorithms consider road topology, car mobility, and link quality to make routing decisions. For instance, GSR [8] detects streets and junctions to avoid obstacles. GPSR-L [9] considers locations and speed of vehicles to calculate the lifetime of neighbors, and the uses this information to efficiently update neighboring tables. The Greedy Perimeter Coordinator Routing (GPCR) [10] is a street-aware protocol, which takes the road topology into account, and it provides a repair strategy to solve the local optimum problem which many geographical routing algorithms may encounter. MURU [11] proposes a metric called Expected Disconnection Degree (EDD) to evaluate the link quality of each intermediate node between the source and destination; EDD represents the probability that the path will be disconnected in some time period. To further improve the path stability in the VANET, some of recent researches rely on the helps of real time or statistical traffic information. For example, A-STAR [12] and ACAR [13] take vehicle density into account to select next hop with better transmission quality. RBVT [14] leverages traffic information to select appropriate road intersections with higher connectivity.

In those works, VANET routing algorithms try to find paths with higher vehicle density, or better link transmission quality to avoid the link being broken. However, those algorithms fail to address issues mentioned previously: While distance between source and destination is significantly increased, the number of hops during routing path is too large. This raises two major problems: First, if any one of links belongs to the path is broken, the communication is interrupted. In fact, frequent disconnections usually happen in VANETs [13] due to channel congestions [15], hidden terminal problems, and other factors. In addition, a VANET is not always connected, which means there may not always exists a route between two nodes [16], and causes routing failures. Some approaches [13] try to adopt store-and-forward mechanism to solve this issue, but the latency may not be acceptable. Second, while the number of hops increases, the latency increases, and makes a large impact on routing performance. Thus, "frequent disconnections" and "too many hops" are important issues in VANET routing. Many works in VANET research focus on the first issue, but cannot efficiently handle the second one.

Since VANET-based V2V systems have disadvantages for traffic information distributions, P2PNavi [3], a two-tier traffic information system, has been proposed to alleviate the above issues by integrating low-tier VANET and high-tier P2P. Each node in P2PNavi is equipped with VANET and P2P network interfaces. In the VANET, 802.11a wireless links are used to communicate between vehicles. In the P2P network, vehicles construct P2P links over Internet through cellular networks. However, only some of vehicles called P2P vehicles enable their P2P interfaces to join the P2P network. To elect P2P vehicles, all vehicles perform a clustering algorithm to elect clusterheads. In this design, P2P vehicles serve as bridges between low-tier VANET and high-tier P2P. When a traffic information lookup is initiated by a cluster member, it is routed through the VANET and also routed through the P2P network by the clusterhead (i.e. P2P vehicle).

With the help of P2P vehicles, P2PNavi solves the problem caused by frequent disconnections in VANET-based V2V systems since lookups through the P2P network can successfully reach destinations when lookups through the VANET cannot. Also, P2PNavi reduces lookup latency compared with pure P2P systems since lookups through the VANET are able to reach destinations efficiently. However, because P2PNavi broadcasts traffic information lookups over two tiers, it introduces significant routing overheads in the VANET and P2P network.

In summary, conventional VANET-based and infrastructure-based V2V systems have their disadvantages for traffic information distributions. Although two-tier traffic information system, i.e., P2PNavi, is able to improve the performance compared with conventional approaches, it introduces large routing overheads and has impacts on cellular network infrastructures.

3. Adaptive Routing Algorithm

3.1. Concept of Routing in Two-Tier Traffic Information System

In original design of the two-tier traffic information system, i.e., P2PNavi [3], the routing procedure is shown in the following figure.

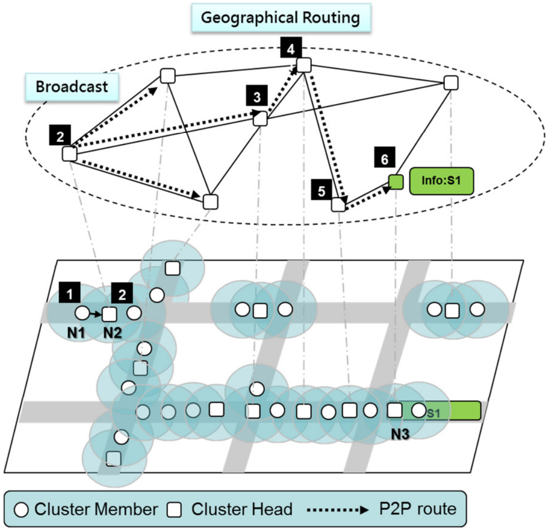


Figure 1: Routing in P2PNavi

In step 1, node 1 initiates a new traffic information lookup to query information of road segment 1. Since node 1 is a cluster member and does not join P2P overlay, node 1 only broadcasts this lookup through the VANET. In the VANET, this lookup will be re-broadcasted until TTL reaches zero. In step 2, node 2 receives this lookup from the VANET and routes this lookup to both the VANET and the P2P network. Node 2 broadcasts this lookup to all of its neighbors in the P2P network. After the first hop of P2P routing, intermediate P2P nodes apply the geographical routing mechanism to find a P2P neighbor with smallest distance toward the destination in step 3. In steps 3-6, geographical routing mechanism is applied again, and finally this lookup reaches the P2P node in the destination segment. In this example, the traffic information lookup is able to reach the destination segment through the VANET and the P2P network. As already mentioned, P2P routing overheads are unnecessary since the lookup through VANET is able to reach the destination with lower latency.

In the following sections, an adaptive algorithm for determining whether a lookup should be routed through the VANET or the P2P network is proposed in detail.

3.2. Design Overview

The main idea of the adaptive routing algorithm is adaptively making routing decisions between the VANET and the P2P network. To achieve this goal, the adaptive routing algorithm must be applied in clusterheads since they control the routing between two tiers. In this way, a two-tier traffic information system is able to select the best route and achieve the following goals:

1. Maintain comparable lookup success rate compared with P2PNavi
2. Reduce unnecessary P2P routing overheads
3. Reduce lookup latency

In order to make routing decisions, the adaptive routing algorithm should estimate the lookup success probability from current node to the destination segment through the VANET. As discussed in chapter 2, factors influences the success routings in VANETs include vehicle densities, congestions, interferences, and hidden terminal problems. In those factors of VANET routing failures, the most important one is vehicle density; it means there may not exist any path between two nodes due to low vehicle density. The issue is critical and should be considered when estimating the success lookup probability, as shown in Figure 2.

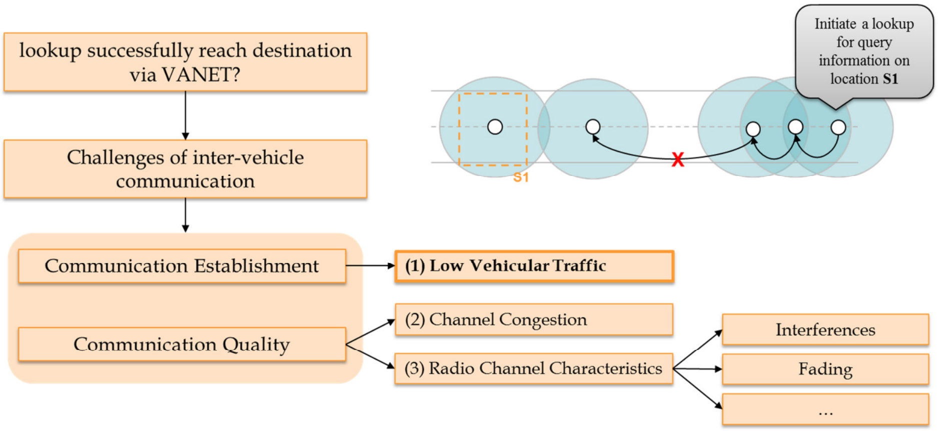


Figure 2: Factors of success lookup via VANET

Therefore, in this study, the success lookup probability is modeled by taking vehicle density into account. The overview of algorithm is shown in Figure 3.

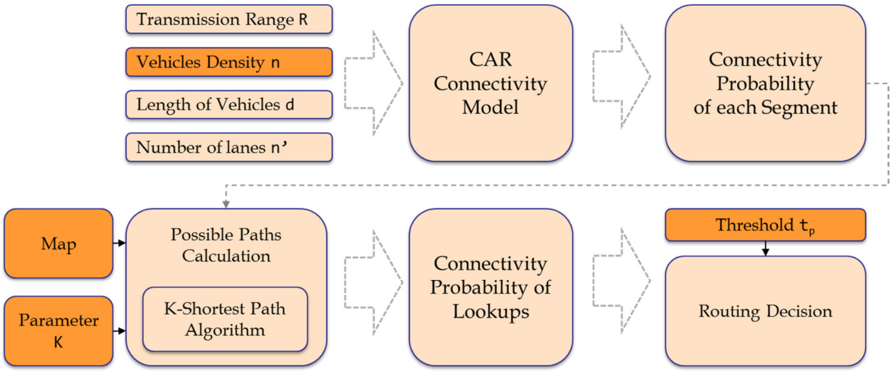


Figure 3: Algorithm overview

First, a connectivity model adapted from [13], which estimates the connectivity probability of single road segment, is adopted in the adaptive routing algorithm. After the connectivity probability of each segment is obtained, the adaptive routing algorithm transforms the road map into a graph and then computes shortest paths from the source vertex to the destination vertex. According to the system parameter k, the lookup connectivity probability is estimated by taking k shortest paths into account. Finally the adaptive routing algorithm makes a routing decision based on a threshold value t_p.

3.3. Connectivity Estimation of Single Road Segment

CAR model [13] is a VANET connectivity model proposed by Qing Yang. It models the connectivity of single road segment with assumption of maximal communication range R.

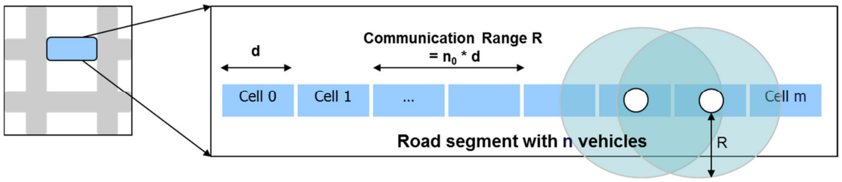


Figure 4: CAR model

The definition of a road segment is the road section between two intersections in grid-based road topology, as shown on the left side of Figure 4. A road segment may consist of multiple lanes of different directions, which depends on road topology. In CAR model, each road segment is divided into m cells, and the size of each cell is the same as average vehicle length d, for example, 5 meters. Thus, each cell can be only occupied by one vehicle. In this way, the connectivity problem can be formulated as follows. The disconnectivity probability is that there are more than n_0 successive empty cells in this road segment, where $n_0 = R/d$. In other words, if the distance between any vehicles in this segment is larger than the maximal communication range, this segment is disconnected.

In one lane case, suppose that the number of vehicles is n and the number of empty cells is denoted as k, then $\mathrm{k} = \mathrm{m} - \mathrm{n}$. Therefore, if $\mathrm{k} \le n_0$, this segment is absolutely connected. If $\mathrm{k} > n_0$, this segment may be connected or disconnected. By applying this concept, the connectivity of each segment is modeled and extended to multiple lanes case in [13]. The disconnectivity probability of a segment is denoted as follows.

$$P_{dis} = \sum_{k=\max(m-n,n_0)}^{\max(m-\lceil n/n' \rceil,n_0)} P\{\mu(n,m)=k\} * P\{\varphi(m,k) > n_0\} \tag{1}$$

Where $\mathrm{P}\{\mu(\mathrm{n},\mathrm{m}) = \mathrm{k}\}$ denotes the probability that there exists exactly k empty cells. Given k empty cells, $\mathrm{P}\{\varphi(\mathrm{m},\mathrm{k}) > n_0\}$ denotes the probability that there exists more than n_0 successive empty cells, and n' is number of lanes.

According to [13], the formula of those terms in equation 1 is shown below:

$$P\{\mu(n,m)=k\} = C_m^k \cdot \frac{C_{(m-k)\times n'}^n}{C_{m\times n'}^n} \cdot \sum_{l=0}^{m-k} C_{m-k}^l \cdot (-1)^l \frac{C_{(m-k-l)\times n'}^n}{C_{(m-k)\times n'}^n} \tag{2}$$

$$P\{\varphi(m,k) > n_0\} = 1 - \frac{\sum_{i=k-n_0}^{\min\{k,(m-k)\cdot n_0\}} c[i]^{m-k}}{C_m^k} \tag{3}$$

Therefore, the connectivity probability of a segment can be obtained by substituting equation 2 and 3 into equation 1. In CAR model, necessary inputs are shown as follows.

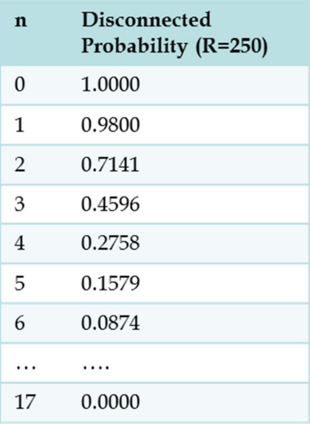
(1) Average vehicle length d

(2) Number of cells in each segment m

(3) Maximal transmission range R

(4) Number of vehicle in each segment (Vehicle density) n

Since the inputs 1, 2 and 3 are static values, the number of vehicles in each segment is the only one variable. As a result, it is able to generate a connectivity table which provides mappings from vehicle densities to disconnectivity probabilities. For instance, assume the average vehicle length is 5m, segment length is 500m, and maximal transmission range is 250m, the connectivity table is shown in Figure 5.



n	Disconnected Probability (R=250)
0	1.0000
1	0.9800
2	0.7141
3	0.4596
4	0.2758
5	0.1579
6	0.0874
…	….
17	0.0000

Figure 5: Connectivity table (R=250m)

According to [13], vehicle density of each segment can be obtained by digital map with traffic statistics, such as average vehicle density at a certain time of the day. In addition, vehicle density of each segment can be collected in real-time by appending density information in lookups and then sent back to initiators through lookup responses. When lookup initiators receive responses, it replaces vehicle density statistics with real-time vehicle density information for later use. In this way, the error of vehicle density can be reduced and make connectivity estimations more accurate.

In summary, given vehicle density of each segment, the disconnectivity probability can be obtained by looking up the connectivity table.

3.4. Connectivity Estimation of Traffic Information Lookup

In this study, the key point of the adaptive routing algorithm is connectivity estimations of traffic information lookups. In previous chapter, the connectivity of each segment has been discussed. To model the connectivity of a lookup, the grid-based road topology is transformed to a graph, as shown in Figure 6.

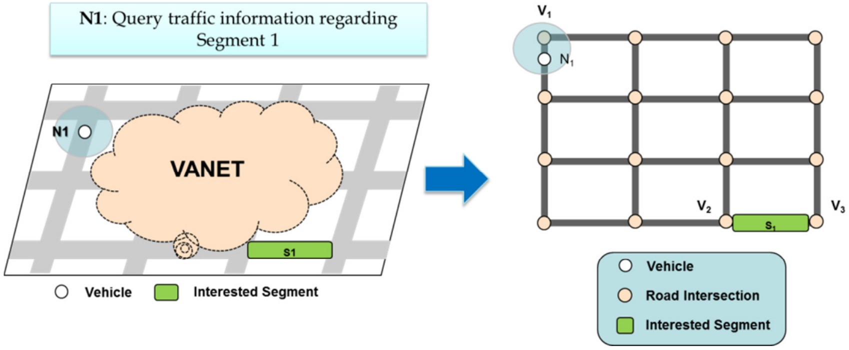


Figure 6: Graph representing road topology

In Figure 6, each vertex represents a road intersection and each edge represents a road segment. Suppose node 1 initiates a traffic information lookup to query information of road segment S_1, the adaptive routing algorithm will first identify that the segment S_1 is located between vertex 2 and vertex 3, and then sets those vertices as the routing destinations. Since the closest vertex near node 1 is V_1, V_1 is selected as the routing source. By applying the connectivity probability of each segment as edge cost, the path with highest connectivity probability can be found by state-of-art shortest path algorithms. In following paragraphs, notations and examples are introduced to explain this concept in more detail.

The estimation of connectivity probability from intersection V_i to road segment S_j by only considering the k shortest path is defined as follows.

$$P_{conn}^{(V_i,S_j)}(k) = MAX(P_{conn}(A_k(V_i,V_a)), P_{conn}(A_k(V_i,V_b))) \qquad (4)$$

Where V_a and V_b is adjacent intersections between road segment S_j; and $A_k(V_i,V_a)$ represents the k shortest path from V_i to V_a without passing intersection V_b and road segment S_j. In other words, when k=1, it means this estimation of connectivity probability is made by considering the shortest path. When k=2, it means this estimation is made by considering the second shortest path, and vice versa.

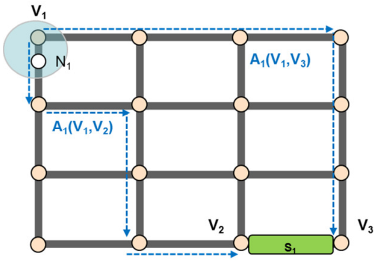


Figure 7: Shortest paths from vertex 1 to segment 1

In addition, the shortest path from V$_i$ to V$_j$ is denoted as $A_1(V_i, V_j)$ and the path cost, which represents connectivity probability of this path, is denoted as $P_{conn}(A_1(V_i, V_j))$.

For example, in Figure 7, $A_1(V_1, V_2)$ is the shortest path from V$_1$ to V$_2$ (without passing V$_3$ and destination segment). Also, $A_1(V_1, V_3)$ is the shortest path from V$_1$ to V$_3$ (without passing V$_2$ and destination segment). Therefore, the connectivity probability estimation of a lookup from V$_1$ to S$_1$ is shown in equation 5.

$$P_{conn}^{(V_1,S_1)}(1) = Max(P_{conn}(A_1(V_1,V_2)), P_{conn}(A_1(V_1,V_3))) \tag{5}$$

However, taking the highest connectivity probability to estimate the connectivity probability of a lookup may be underestimation since multiple paths are tried by broadcasting packets in the VANET, as shown in the following figure:

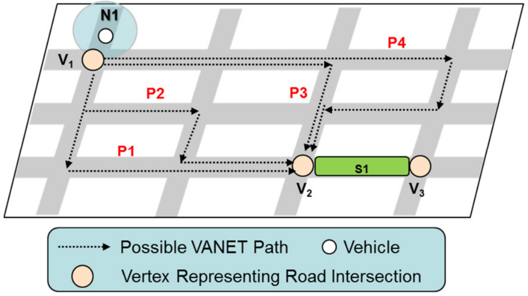


Figure 8: Multiple paths from vertex 1 to vertex 2

Because the number of possible paths may be large in large-scale road topology, it is not practical to estimate connectivity probability by all possible paths. Thus, the adaptive routing algorithm takes the k shortest paths into account to estimate connectivity probability of a lookup. Computing k-shortest paths has been a popular research topic since the 1950s [17]; several k-shortest paths (KSP) algorithms are available nowadays, such as YEN [18] and

Katoh [19]. However, most of KSP algorithms try to find k-shortest paths which may be overlapped, such as P3 and P4 in Figure 8. Because routing lookups through overlapped paths are not independent events, those algorithms may not feasible since it is too complicated to compute the connectivity probability of a lookup through overlapped paths at runtime.

As a result, in order to estimate the connectivity probability of a lookup with acceptable computing overheads, the adaptive routing algorithm computes k-disjoint-shortest paths rather than overlapped shortest paths. In this way, the connectivity probability of a lookup from V_1 to S_1 can be estimated as follows.

$$P_{succ}(K,V_1,S_1)=1-\prod_{k=1}^{K}(1-P_{conn}^{(V_1,S_1)}(k)),\text{ where } P_{conn}^{(V_1,S_1)}(k)=P_{conn}(A_k^{dis}(V_1,(V_2,V_3))) \tag{6}$$

The generalized form of above equation is:

$$P_{succ}(K,V_i,S_j)=1-\prod_{k=1}^{K}(1-P_{conn}^{(V_i,S_j)}(k)),\text{ where } P_{conn}^{(V_i,S_j)}(k)=P_{conn}(A_k^{dis}(V_i,(V_a,V_b))) \tag{7}$$

In equation 7, V_i is the road intersection as routing source, S_j is the road segment as routing destination, $A_k^{dis}(V_i,(V_a,V_b))$ is the k-disjoint-shortest path from V_i to (V_a or V_b), and then $P_{succ}(K,V_i,S_j)$ represents the probability that "at least one path is connected."

Once the connectivity probability of a lookup is obtained, the adaptive routing algorithm makes a routing decision based on a threshold t_p. If P_{succ} is larger than t_p , it routes this lookup to the VANET as next hop and does not forward this lookup to the P2P network anymore. In the case that P_{succ} is less than t_p, the standard P2PNavi routing is applied to determine the next hop. The pseudo code of adaptive routing algorithm is shown below.

Adaptive Routing Algorithm: doClusterheadRoutingDecision()

```
doClusterheadRoutingDecision()
{
    If (Routing Mechanism == VANET ROUTING)
    {
        Route to VANET
    }
    Else If (Routing Mechanism == P2P ROUTING)
```

```
{
    Route to P2P
}
Else If (Routing Mechanism == P2PNavi ROUTING)
{
        IF (Packet is received from P2P interface)
            Route to P2P
        ELSE IF (Packet is received from VANET interface)
        {
            IF(Current vehicle is the clusterhead of original sender)
                Route to VANET and P2P
            ELSE
                Route to VANET
            }
    }
    Else If (Routing Mechanism == ADATPIVE ROUTING)
    {
        IF (This packet is already processed by Adaptive Routing)
        {
            Skip Adaptive Routing Algorithm
            Perform P2PNavi Routing Algorithm
        }
        Condition 1 =   Packet is received from P2P
        Condition 2 =   Packet is received from VANET and I'm clusterhead of original sender
        Condition 3 =   Current vehicle is not stopped
        IF ((Condition 1 || Condition 2) && Condition 3)
        {
          VANETConnProbability = getConnectedProbability()
          IF (VANETConnProbability > Threshold)
          {
            Route Packet to VANET;
          }
          ELSE
          {
            Perform P2PNavi Routing Algorithm
          }
        }
        ELSE
```

```
                    Perform P2PNavi Routing Algorithm
            }
        }
```

Figure 9: Pseudo code : doClusterheadRoutingDecision

Adaptive Routing Algorithm: getConnectedProbability()

```
Dest_SegId: Destination Road Segment ID
Parameter_K: control the number of shortest paths need to be considered

getConnectedProbability()
{
    Src_Vertex = get Closest Intersection from current location;
    Dest_Vertex1 = get first vertex of destination segment;
    Dest_Vertex2 = get second vertex of destination segment;

    Return Get_MaxConnectivity_TwoDestVertex(Parameter_K, Dest_SegId, Src_Vertex,
            Dest_Vertex1, Dest_Vertex2)
}
```

Figure 10: Pseudo code : GetConnectedProbability

Adaptive Routing Algorithm: Get_MaxConnectivity_TwoDestVertex ()

```
GraphBase : the graph representing road topology

Get_MaxConnectivity_TwoDestVertex ()
{
   Graph_Without_V1 = get Duplicated Graph from GraphBase;
   Graph_Without_V2 = get Duplicated Graph from GraphBase;

   Graph_Without_V1 = Remove destination segment(Dest_SegId) and edge(Dest_Vertex1);
   Graph_Without_V2 = Remove destination segment(Dest_SegId) and edge(Dest_Vertex2);

   Path_A1_Dest_Vertex1 = doDijkstraAlgorithm(Graph_Without_V2, Src_Vertex, Dest_Vertex1)
   Path_A1_Dest_Vertex2 = doDijkstraAlgorithm(Graph_Without_V1, Src_Vertex, Dest_Vertex2)

   Cost_V1 = getPathCost(Path_A1_Dest_Vertex1);
   Cost_V2 = getPathCost(Path_A1_Dest_Vertex2);
```

```
    IF(Cost_V1 > Cost_V2)
    {
      RetValue = Cost_V1;
      RetPath = Path_A1_Dest_Vertex1;
    }
    ELSE
    {
      RetValue = Cost_V2;
      RetPath = Path_A1_Dest_Vertex2;
    }
    IF(Parameter_K == 1) Return RetValue;

    IF(Parameter_K > 1)
    {
      Graph = RemovePath(GraphBase, RetPath);
      /* Repeat this procedure to find K disjoint shortest Paths by removing found paths from the
      graph */
    }
}
```

Figure 11: Pseudo code : Get_MaxConnectivity_TwoDestVertex

4. Simulation Results

4.1. Simulation Environment

4.1.1. Overview

To evaluate the performance of proposed adaptive routing algorithm, Qualnet network simulator [20] is used. In addition, in order to obtain realistic vehicle mobility traces, vehicle traces are generated by simulation of urban mobility (SUMO) [21] traffic simulator.

As mentioned, CAR model [13] provides mappings from vehicle densities to disconnectivity probabilities of a segment. In the simulation, CAR model is implemented independently outside of the network simulator for computing connectivity tables. Connectivity tables are generated and saved for later use.

In simulations, the road topology is Manhattan-style road topology (i.e. grid-based), and dimension is 1500 meters by 1500 meters. Each road has one lane per direction. There are no traffic lights at intersections. The number of vehicles varies from 100 to 500 in scenarios, and each scenario is simulated for 200 seconds and 20 runs.

Each vehicle is equipped with both the VANET and the P2P network interfaces. The VANET interface is simulated by IEEE 802.11a in ad-hoc mode; antenna type is omni-directional, communication range is 250 meters, propagation model is two-ray, and fading model is Rayleigh fading model. Since the assumption of P2P network in this study is an "always on" link, the P2P network interface is simulated by single switch-based 802.3 LAN with 100Mbps bandwidth. To simulate P2P link latency, P2P packets are delayed for 250 ms whenever they are sent. This value of link latency is based on the practical experiments in [2].

4.1.2. Two-Tier Architecture

The implementation of the two-tier traffic information system can be divided into two parts: low-tier VANET and high-tier P2P. The basic architecture of this system is the two-tier approach using the unstructured P2P system as described in [3].

In low-tier VANET, vehicles broadcast hello messages periodically to know their neighbors and exchange traffic information within one hop. In addition, vehicles perform lowest-ID clustering algorithm [1] periodically to elect clusterhead and construct 1-hop cluster. For lookup routing, vehicles rebroadcast lookups when they receive lookups from the VANET interface. If Time-to-Live (TTL) of lookup reaches zero, this lookup is dropped and would not be rebroadcasted. To avoid broadcast storms, a node does not rebroadcast a given lookup more than once [22].

In high-tier P2P, clusterheads (i.e. P2P vehicles) connect to a P2P bootstrap server to obtain a list of active P2P vehicles. P2P vehicles then establish connections to some of vehicles in the list to construct an unstructured P2P overlay. The maximal size of P2P neighboring table is 15. In addition, P2P vehicles periodically send ping messages to their P2P neighbors. If any neighbor does not respond ping message, this neighbor is deleted from the neighbor table. Once the size of P2P neighboring table is below a threshold, P2P vehicles ask the bootstrap server or their P2P neighbors for more P2P neighbors.

The routing mechanism in P2P network is varied by different routing algorithms. The original routing algorithm of two-tier traffic information system (P2PNavi) [3] is already described in chapter 3.1: If it is the first hop, P2P vehicles broadcast lookups to all P2P neighbors; otherwise, geographical routing is performed. On the other hand, the routing decision is made adaptively if the adaptive routing algorithm is activated.

4.1.3. Lookup Traffic Generation

In order to simulate traffic information lookups, a traffic lookup list is generated at start of simulation. This list includes source vehicle ID and lookup initialization time. In the list, both source vehicle ID and traffic initialization time are chosen randomly. Each vehicle checks this list to decide whether it should send traffic lookup or not. Although the source vehicle and lookup sending time are decided at initialization, the destination segment of each lookup is decided by randomly selecting a segment with at least one vehicle at the time of initiating lookup.

Finally, the following table summarizes simulation parameters:

Table 1: Simulation Parameters

Parameter	Value
Road Topology Parameters	
Map dimensions	1500 x 1500 meters
Road segment length	500 meters
Number of lanes	1 lane per direction
Number of road segments	24
Vehicle density	4 ~ 20 vehicles/km
Vehicle speed limit	50 km/hr (14 m/s)
Low-tier VANET Parameters	
Wireless communication range	250 meters
Wireless PHY	802.11a
VANET ping period	3 seconds
VANET clustering period	9 seconds
VANET neighbors expiration	5 seconds
VANET lookup TTL	10
High-tier P2P Parameters	
P2P Link Latency	250 milliseconds
P2P neighboring table size	15
P2P lookup TTL	7
P2P stabilization period	3 seconds
P2P neighbors expiration	5 seconds

4.2. Simulation Results

In simulations, we evaluate the performance of proposed adaptive routing, denoted as adaptive, P2PNavi [4] routing, denoted as P2PNavi, and pure VANET routing, denoted as VANET. For adaptive routing, performance of different connectivity probability thresholds (P) and parameters (K) is evaluated.

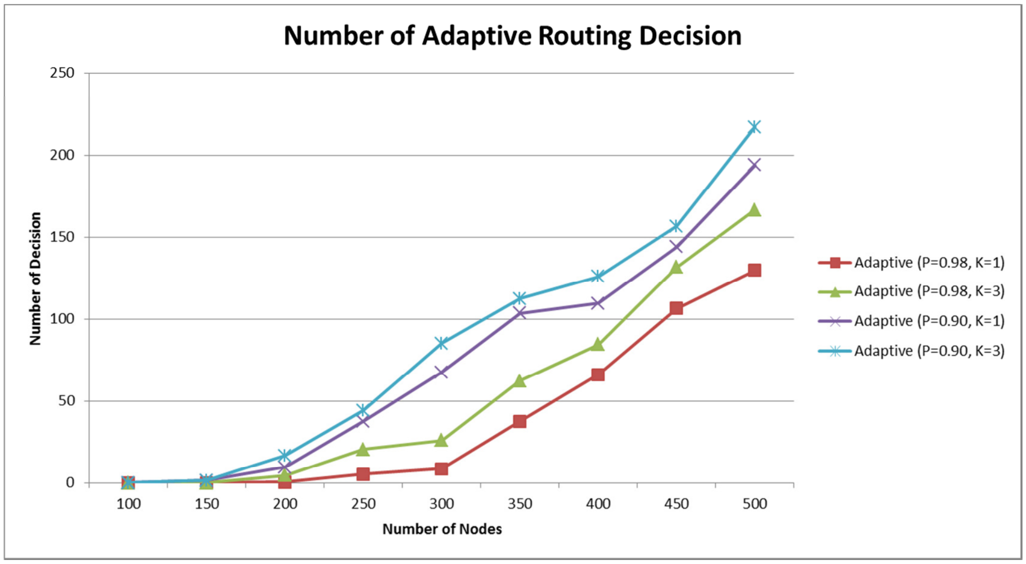


Figure 12: Number of adaptive routing decisions

To understand the effect of adaptive routing decisions, Figure 12 show the number of adaptive routing decisions under different number of vehicles. The definition of adaptive routing decisions is that a lookup is routed from high-tier P2P to low-tier VANET by the adaptive routing algorithm.

In the scenarios where the number of vehicle is less than 200, adaptive routing does not make any adaptive routing decisions. The reason is that the VANET has very low connectivity but the connectivity probability threshold is set above 0.9.

As shown in Figure 12, the number of adaptive routing decisions increases when the number of vehicle increases. For the same connectivity probability threshold P, the estimation of the shortest path (K=1) makes less routing decisions than that of multiple paths (K=3) due to underestimations. In other words, for each lookup, if more paths are taken into account, it may get higher connectivity probability estimations and have more chances to be routed to low-tier VANET. Moreover, for the same parameter K, the system with higher connectivity probability threshold (P=0.98) made less adaptive routing decisions because only few lookups have high connectivity estimations.

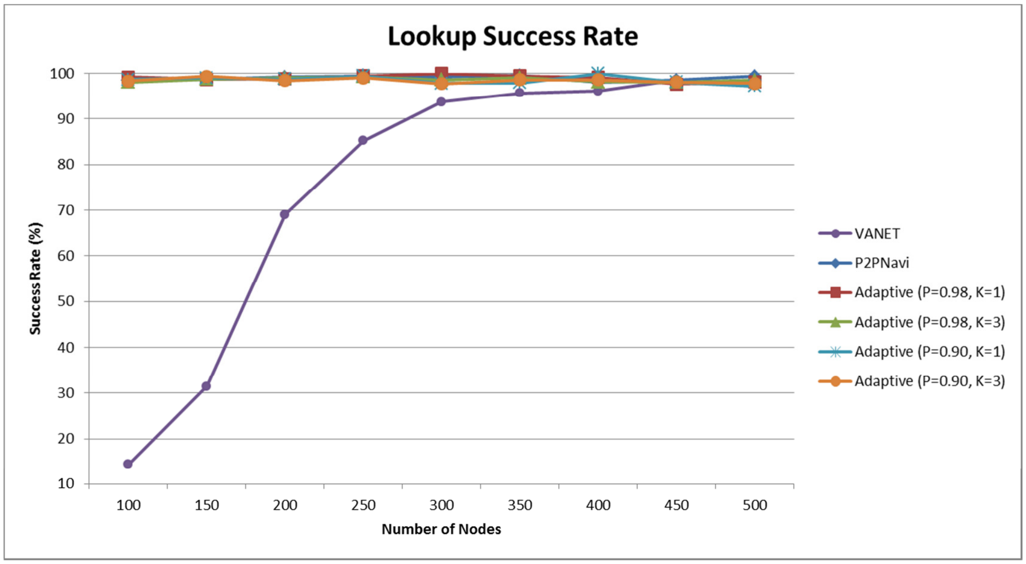


Figure 13: Lookup success rate under different number of vehicles

Figure 13 shows the lookup success rate under different number of vehicles. Because network connectivity increases as the number of vehicles increases, success rate increases for pure VANET routing.

In this result, both P2PNavi and the adaptive routing algorithm achieve high success rate under different number of vehicles. However, the adaptive routing (P=0.9, K=3) has little tendency towards lower success rate due to low estimation correct rate (It will be discussed later). This result demonstrates that adaptive routing algorithm can still maintain almost the same lookup success rate compared with original P2PNavi.

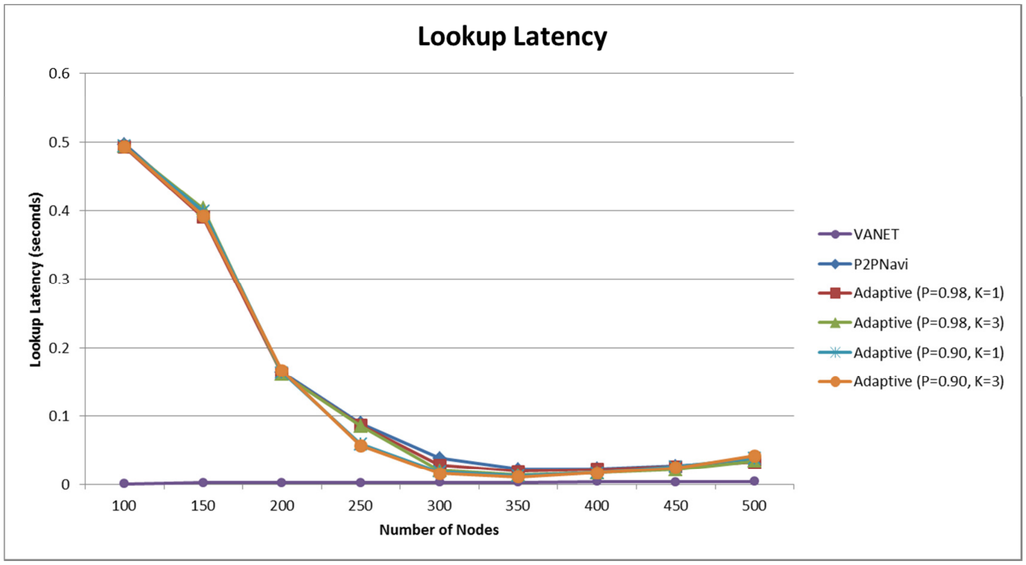


Figure 14: Lookup latency under different number of vehicles

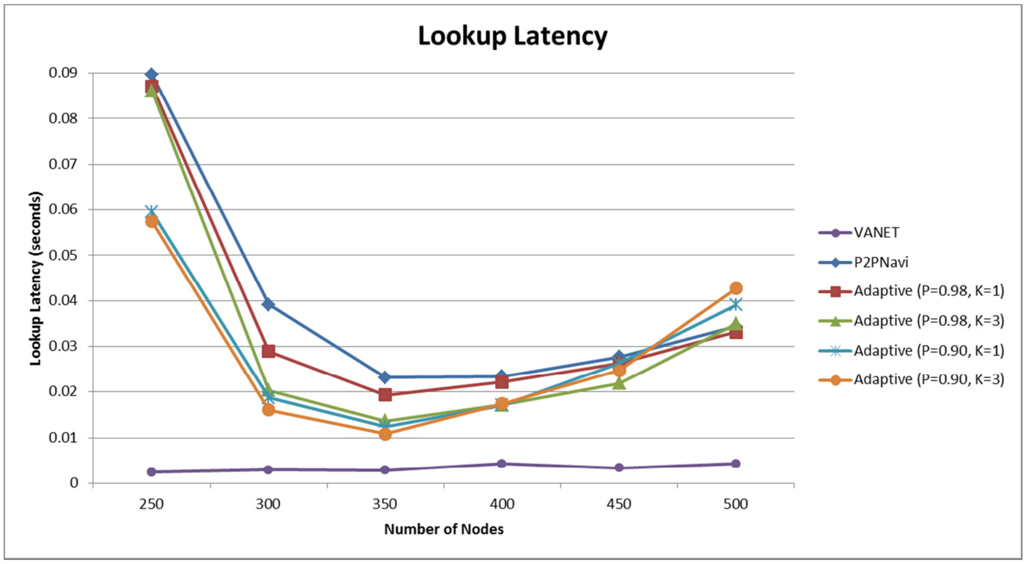


Figure 15: Lookup latency under different number of vehicles (Cropped)

The lookup latency is shown in Figure 14 and Figure 15. In all cases, pure VANET routing has the lowest lookup latency because of link characteristics. However, Figure 13 indicates that pure VANET routing has poor lookup success rate. In contrast, P2PNavi and the adaptive routing algorithm have higher latency since large use of P2P links. However, while node density increases, the lookup latency is reduced since more VANET links are used.

When P=0.98, the adaptive routing algorithm reduces lookup latency by 16% to 48%; When P=0.9, the adaptive routing algorithm significantly reduces lookup latency by 20% to 59%. The reason is that adaptive routing algorithm will route lookups from the P2P network to the VANET once it detects the VANET is connected from current location to the destinations, but P2PNavi continues to forward lookups until lookups reach the destination. In other words, the adaptive routing algorithm has lower lookup latency when partial VANET disconnections occur. Nevertheless, the latency reduction becomes smaller when the number of vehicles increases; once the partial VANET disconnections are not happened, P2PNavi and the adaptive routing algorithm (P=0.98) has almost the same lookup latency.

On average, the adaptive routing algorithm (P=0.9) achieves lower latency than the adaptive routing algorithm (P=0.98) since more adaptive routing decisions are made.

However, when node number is larger than 400, the adaptive routing algorithm (P=0.9) has much higher latency than the adaptive routing algorithm (P=0.98) and P2PNavi. The reason is that a lot of lookups are redirected from high-tier P2P to low-tier VANET and network congestions occur.

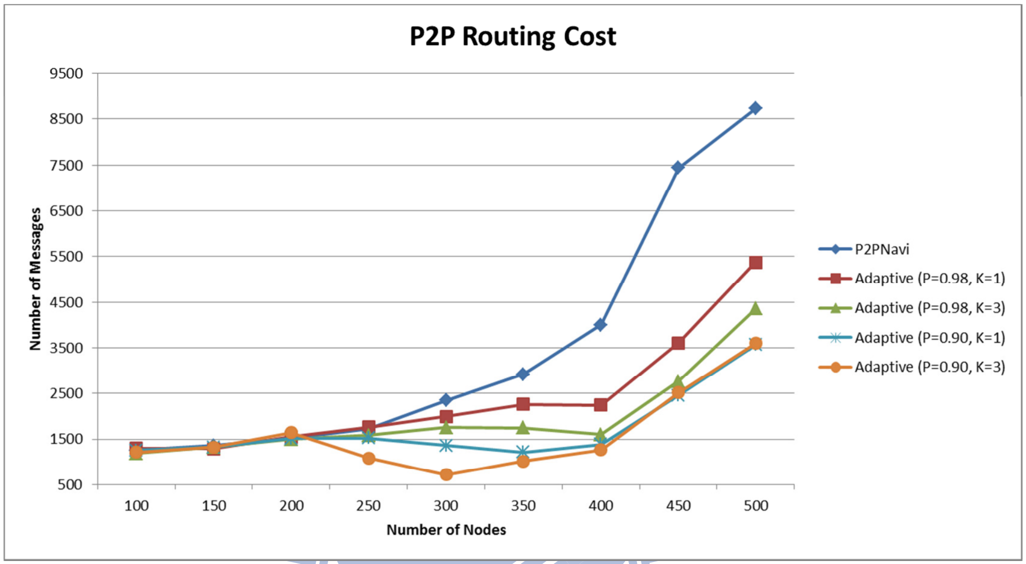


Figure 16: P2P routing cost under different number of vehicles

In Figure 16, P2P routing cost of both P2PNavi and the adaptive routing algorithm increases while the number of vehicles increases. Since adaptive routing algorithm is able to detect the VANET connectivity and route lookups to the VANET when the number of vehicles is sufficient, adaptive routing algorithm significantly reduces P2P routing cost in scenarios with 250-500 nodes. For example, when the number of vehicle is 350, adaptive routing (P=0.98, K=3) reduces P2P routing cost by 40%. Moreover, when vehicle number is 500, adaptive routing (P=0.98, K=3) reduces P2P routing cost by 47%. In this result, the adaptive routing (P=0.9, K=3) introduces maximal reduction of routing latency up to 70% when node number is 350. This result shows that adaptive routing algorithm can significantly reduce P2P routing overhead in the two-tier traffic information system.

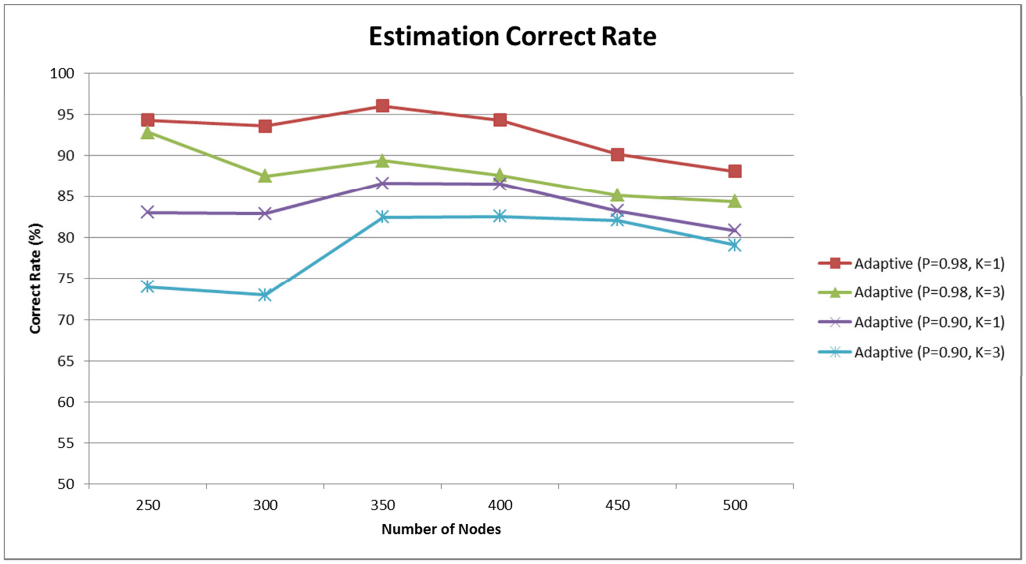


Figure 17: Estimation correct rate

The estimation correct rate is shown in Figure 17. When adaptive routing algorithm makes a decision to route a lookup from high-tier P2P back to low-tier VANET, an adaptive routing ID is assigned to this lookup. Once a lookup with this adaptive routing ID successfully reaches the destination, this estimation is counted as a correct estimation.

On average, adaptive routing (P=0.98, K=1) achieves 92% estimation correct rate, and adaptive routing (P=0.98, K=3) achieves 86% estimation correct rate. Because traffic lookups are broadcasted (and duplicated) in the VANET, few estimation failures would not cause lookup failures. Note that adaptive routing (P=0.9, K=3) achieves only 79% estimation correct rate on average and causes small downgrade of lookup success rate, as already shown in Figure 13.

However, all curves in Figure 17 slightly decrease as the number of vehicles increases. The main reason is that many vehicles wait behind road intersections due to traffic jams, as shown in Figure 18.

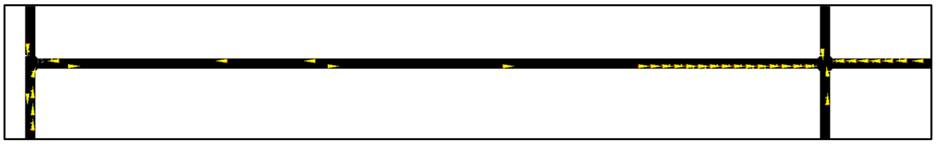


Figure 18: Vehicular traffic in scenario with 500 vehicles

In this case, a lot of vehicles block behind road intersections, resulting in errors of connectivity estimations: There are only small portion of vehicles can support lookups to pass through the road segment, even the total number of vehicles in the segment is large. This problem of CAR model can be alleviated by installing traffic lights in all intersections [13]. However, this problem may still persist in the situation where traffic light period is dynamic and could be a future work of this study.

5. Conclusions and Future Works

In this study, an adaptive routing algorithm for the two-tier traffic information system has been proposed and implemented. In this algorithm, the connectivity probability of a road segment is discussed and the connectivity probability of a lookup through the VANET is estimated; most importantly, routing decisions are made to adaptively route traffic information lookups between low-tier VANET and high-tier P2P.

The simulation results show that the proposed adaptive routing algorithm provides significant reduction of P2P routing costs, which is up to 70% compared to P2PNavi routing algorithm while maintaining comparable lookup success rates. Moreover, in the scenario with middle vehicle densities, the adaptive routing algorithm can significantly reduce lookup latencies by 59% compared to P2PNavi routing algorithm.

Currently, the adaptive routing algorithm estimates the connectivity probability by taking vehicle densities into account. However, other factors, such as interferences, collisions, and channel congestions, may have impacts on traffic information lookups through the VANET; those factors are usually happened when the number of nodes is extremely large or too many lookups are sent. In addition, the effect of traffic jams around intersections is also an important issue, which causes the error of CAR model. If those factors can be taken into account when estimating success probability of lookups through the VANET, it still has room for improvement of adaptive routing algorithm in the two-tier traffic information system.

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