CHAPTER 2

METHODOLOGY

2.1 PROBLEM FORMULATION

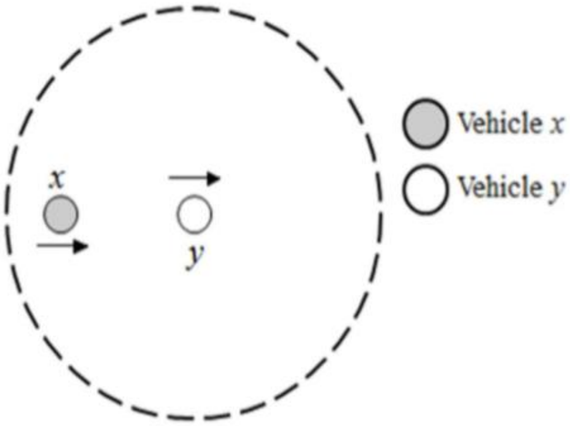

Fig 2.1 Proposed V2V method

In the proposed method, each vehicle x reports/transmits its context, containing the location derived using GPS, speed, direction, IDs of the vehicles that x can detect beacons from, through BSs, to the context database of the SDNi-MEC server periodically. The SDNi-MEC server can generate rules for vehicles using messages and events. Table I and Table II contain the messages and events that are used. The messages include the initialized message (V2C), the reporting message (V2C), the switch message (C2V), the repaired message (V2C), the dropped message (V2C) and the end message (C2V); the events include the packet sending event, the reporting event, the VANET path event, the recovery event, the packet dropping event and the lifetime end event. Let $lt_{(u,v)}$ denote the connection lifetime between vehicles u and v, where $lt_{(u,v)}$. Let $lt_{(u,v)}$ denote the connection life time between vehicles u and v, where $lt_{(u,v)}$ 0. After receiving the reported vehicle contexts, the SDN Controller of the SDNi-MEC server can derive the connection lifetime $lt_{(x,\ y)}$ between vehicles x and y. The connection life time $lt_{(x,y)}$ between any two vehicles is varied and decided by their relative distance and relative velocity. After receiving the reported vehicle contexts, the SDN Controller of the SDNi-MEC server can derive the connection lifetime $lt_{(x,\ y)}$ between vehicles x and y. The connection lifetime $lt_{(x,y)}$ between any two vehicles is varied and decided by their relative distance and relative velocity. Let vehicle x denote the send er and vehicle y denote the receiver. Referring to Figure, two cases of the connection lifetime between vehicles x and y are as follows.

Case1: Vehicle x is behind vehicle y, in the same direction (Vx > Vy).

Case2: When x is behind y, and they are leaving each other in the same direction (Vx < Vy).

Case3: x is ahead of y, and y can catch up with x in the same direction (Vx <Vy).

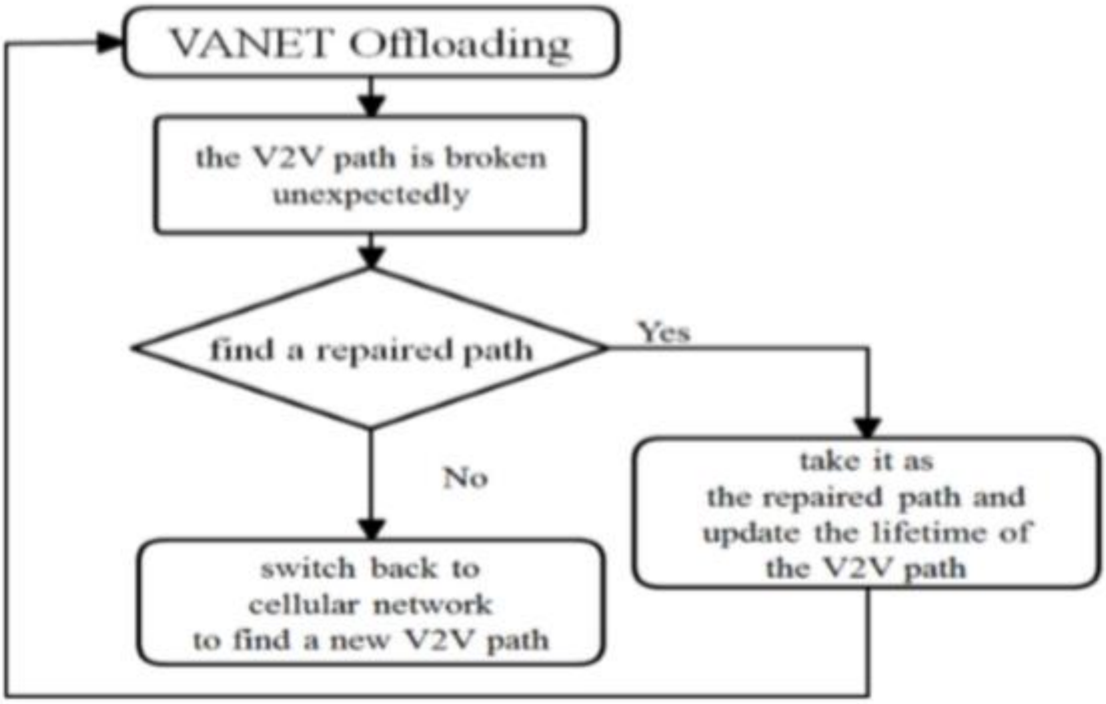

Figure 2.2 The execution procedure of recovering/repairing a V2V path.

V2V path for vehicles x and y based on the received context reported/transmitted from all of the vehicles that want to have the V2V offloading or not, how to find the better V2V path when there are many paths and how to repair/recover a broken path? In this work, the LifeTime-based Network State Routing (LT-NSR) algorithm and the LifeTime-based Path Recovery (LT-PR) algorithm are proposed to resolve the aforementioned 3 issues.

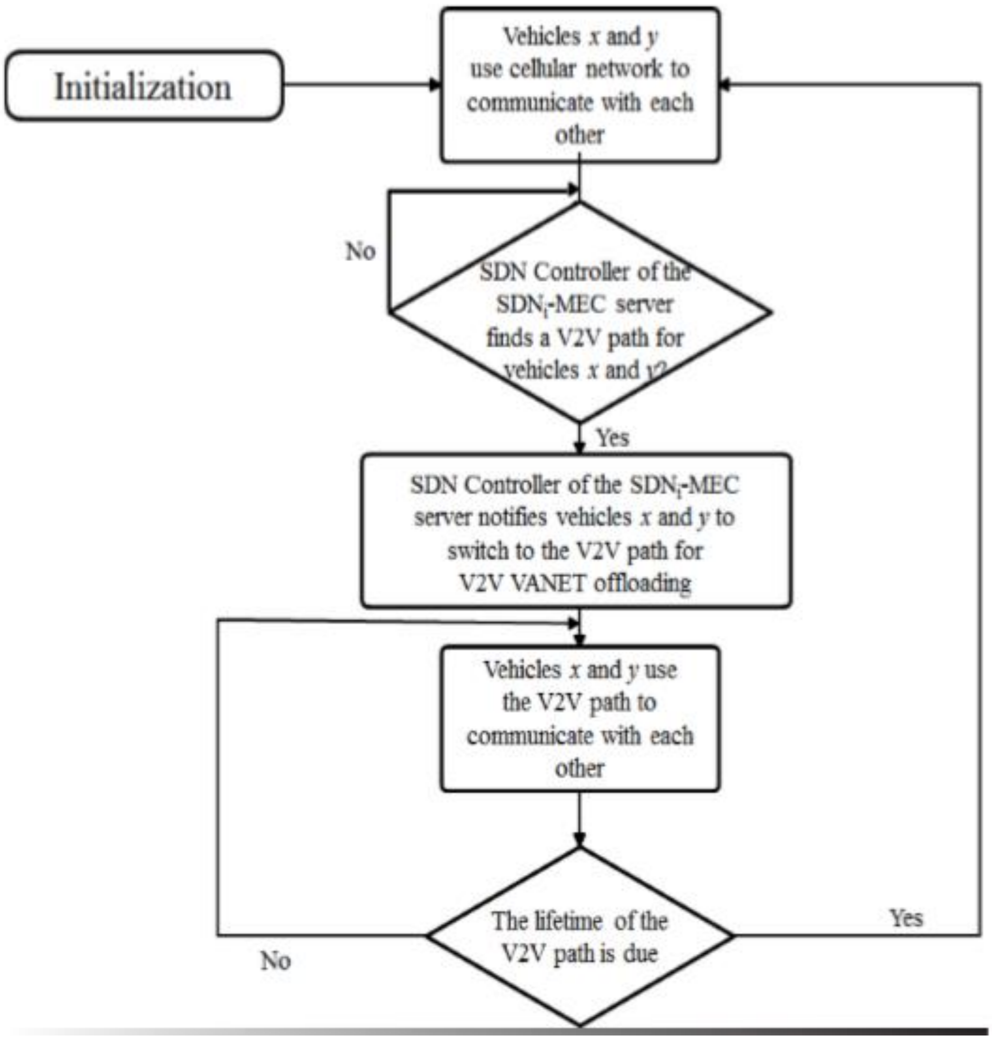

Figure 2.3 The execution procedure of having the V2V VANET offloading.

The functional scenario is as follows, and the corresponding execution procedure is depicted in Figure 4. Initially, let the peered vehicle x and vehicle y that want to communicate with each other use the cellular network. Vehicles x, y and others that want to adopt the V2V VANET offloading function report/transmit their contexts to the SDNi-MEC server periodically.

- SDN Controller of the SDNi-MEC server keeps checking whether there is a suitable V2V path,whichisv1 → v2 →···→ vn, between vehicles x and y or not. For example, the path v1 →v2 →v3 that exists between x and y.
- If it exists, then it denotes that v1, v2,...,vn can play the relay nodes that are able to forward packets from vehicle x/y to vehicle y/x. Thereafter, SDN Controller in the SDNi-MEC server

notifies vehicles x, v1, v2,...,vn, y to establish a V2V path in their routing tables and vehicles x and y to be able to use the V2V path (x → v1 → v2 → ⋯ → vn → y) for their communication.

- Vehicles x and y then switch their communication path from the cellular network to the VANET network. At the same time, all of the vehicles x, v1,v2,...,vn and y keep uploading/transmitting their context to the context database of the SDNi-MEC server through BSs
- The V2V VANET offloading is ended when the expected lifetime of path (x → v1 → v2 → ⋯ → vn →y) is due, when the path is broken earlier, which results from one or more vehicles change their speed, or when the path is broken suddenly because a vehicle changes its direction and speed very fast.
- When the V2V VANET offloading is ended, vehicles x and y switch the communication path from the V2V VANET network back to the cellular network.

A vehicle may change its speed or direction, e.g., detour to the other road in the road interaction point, which results in breaking the V2V path. Some recovery actions can be devised to tackle the exception handling. Let vehicle vi+1 be going to run away and vehicle vi be the previous vehicle of vi+1 and vehicle vi+2 be the next vehicle of vi+1 in the V2V path. A mechanism can be devised to try to recover/repair the broken V2V path by replacing the drive-away vehicle vi+1 with the other neighboring vehicle, which can communicate with vi and vi+2 directly, such that the V2V path can be kept. Note that the lifetime of the recovered/repaired V2V path may become longer or shorter after the path is recovered/repaired. The execution procedure of the path recovery is depicted in Figure 6 and explained as follows:

2.2 THE PROPOSED ALGORITHM 1

```
for each node v do // set the connection's lifetime of each neighbour of source s
    if c is a neighbour of s then
        D(v) = lt(s, v)
    else
        D(v) = -1
```

```
    end if
end for
S0 = {s}
repeat
    find w not in S0 such that D(w) is the maximum among all D(v)
        padd w to S0
    // update node's lifetime
    for each neighbour u of w do
        if u ϵ S0 and min{ D(w), lt(w, u) } > D(u) then
            D(u)=min{ D(w), lt(w, u) }
        end if
    end for
until d ϵ S0
return S
```

- At the beginning of exploration, in which the S0 set only contains source s, it derives D(v) for each neighbour v of s.
- After deriving the lifetime of each link, LT-NSR chooses vehicle w, which is not in S0, and D(w) is the maximum among all D(v), and then w is added to S0.
- Once vehicle w is added to the S0 set, each of w neighboring nodes that are not in the S0 set needs to update the lifetime of the path between s and itself.
- LT-NSR explores the topology repeatedly until destination d is contained in S'.

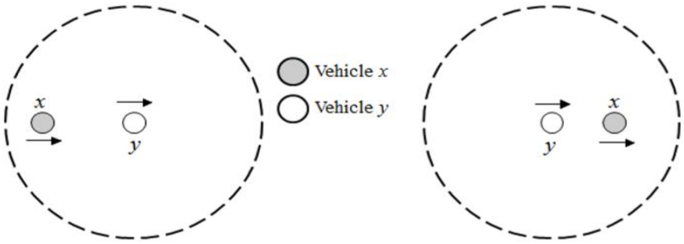

Figure 2.4 The configurations for connection's lifetime derivation.

2.3 LIFETIME-BASED NETWORK STATE ROUTING

When vehicles transmit packets through cellular networks, the source vehicle s sends an initialized message, which represents a packet sending event, to the SDNi-MEC server. This message/event triggers the SDN controller of the SDNi-MEC server to find a V2V routing path from source vehicle s to destination node d. Hereafter, data packets between s and d are transmitted and s, d, and other relay nodes report/transmit their contexts (location, speed, direction and IDs of neighbouring vehicles) periodically to the context database of the SDNi-MEC server using the reporting message, which is through the cellular network. Since there are many vehicles running on the road at any time, there may not be just one V2V routing path between vehicle s and d.

To find and ensure that the path is optimal, the Life Time-based Network State Routing (LT-NSR) algorithm is proposed. The SDN Controller of the SDNi-MEC server can use LT-NSR to derive the optimal k-hop V2V routing path, for which the k-hop V2V routing path has the longest lifetime based on the current VANET situation.

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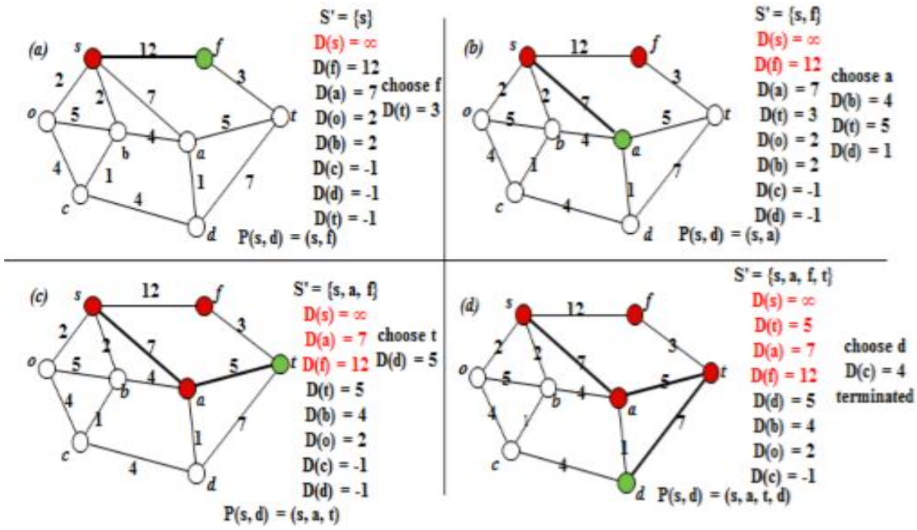

Figure 2.5 An example of executing the LT-NSR algorithm.

V2V routing path between vehicle s and d. To find and ensure that the path is optimal, the LifeTime-based Network State Routing (LT-NSR) algorithm is proposed. The SDN Controller of the SDNi-MEC server can use LT-NSR to derive the optimal k-hop V2V routing path, for which the k-hop V2V routing path has the longest lifetime based on the current VANET situation.

The exploration of the path P(s, d) is ended in the 4th iteration, which is depicted in and the selected path is (s, a, t, d), whose lifetime is 5, the complexity of algorithm LT-NSR (s, d) is analysed as follow. Let the number of vehicles between s and d be n. For loop of LT-NSR(s, d) needs n iterations to finish. The repeat loop started from Line9 is stop until d is included in S0, which needs n iterations to finish; for loop started from Line 13 needs n iterations to finish. As a result, the total complexity of the statements is O(n□n) in the worst case. Thus, the complexity of LT-NSR (s, d) is O(n2).

Let D(v) denote the set of connection life times for all paths P lt(s, v) between vehicle s and each of the vehicles that have been considered and let S0 denote a set of those vehicles that have been currently selected as member vehicles of the path. Algorithm 1 is the pseudo code of the LT-NSR algorithm.

Let P(v1, vn) denote a path that consists of a sequence of vehicles V = {v1, v2,...,vn}, and the lifetime between the paired vehicles i and i+1 is denoted as lt(v1, v2), lt(v2, v3),...,lt(vn−1, vn) respectively, i.e., lt(vi, vi+1), i = 1,...,n−1.The lifetime between sand v1 is denoted as lt(s, v1), and the lifetime between vn and d is denoted as lt(vn, d). Plt(s, d) denotes the connection lifetime of path P(s, d) through s, v1, v2,...,vn,d, which is derived as follows: P lt(s, d)=min{ lt(s,v1), lt(v1,v2),...,lt(vn−1,vn), lt(vn,d) }

2.4 V2V VANET OFFLOADING

When the SDN controller of the SDNi-MEC server finds a routing path between s and d, it sets the new rule using the VANET path event and sends the switch message to inform vehicles. When the vehicles receive switch messages, they update their routing tables. When the connection between s and d is switched to a V2V path, the V2V path has its own connection lifetime that decreases over time. When the V2Vpathisended, sources transmits the end message to the SDNi-MEC server to trigger the lifetime end event. At that time, source s and destination d communicate with each other through the cellular network. Additionally, the SDN controller of the SDNi-MEC server would try

to find the other V2V routing path between s and d. However, a V2V path may be broken because some vehicles run away unexpectedly. In this situation, the V2V VANET offloading is broken and packets that are temporarily stored in relay vehicles should be dropped. The corresponding relay

vehicle that dropped packets back-traces to source s and then s transmits the dropped message to the SDNi-MEC server, which is denoted as a packet dropping event. This packet dropping event triggers the SDN controller of the SDNi-MEC server to respond: Flow Removed to remove the V2V path.

2.5 LIFETIME-BASED PATH RECOVERY (LT-PR)

The lifetime of the V2V path is derived and calculated by the SDN controller of the SDNi-MEC server. In the process of offloading, some deviations may occur such that the V2V path is broken earlier then its originally expected lifetime. Using the proposed recovery/repair method, the corresponding V2V path can be kept, which may result in extending or shortening the lifetime. LT-PR is triggered by the repair message, which represents the recovery event, sent to the SDNi-MEC server. The pseudo code for LT-PR. Let R0 denote the set of candidate vehicles that can be selected, vi+1 denote the run-away vehicle, vi denote the previous vehicle and vi+2 denote the next vehicle. Note that vi+1 may still receive the hello message from vi or vi+2, if vi+1 is still in the signal coverage of vi or vi+2 or if vi cannot communicate with vi+1 but vi+1 can still connect to vi+2 directly. However, vehicle vi+1 should not be a candidate because vi+1 is going to run away. These candidates are selected from the neighbors of vi that are also the neighbors of vi+2, i.e., those vehicles that can receive the hello messages from both vi and vi+2, and then are added into R0. There is a special case where vi become sable to connect to vi+2 directly. Thus, vi+2 is set as the target vehicle Vr and the temporary lifetime of this path is set as the lifetime between vi and vi+2, which is 0 if they are not connected directly. If LT-PR cannot find a repaired V2V path, which means no candidate can be the repaired node, the packet dropping event is triggered by the SDN controller of the SDNi-MEC server.

2.6 THE PROPOSED ALGORITHM 2

```
R’ = {}
for each neighbour x of vi do
    if x also receives vi+2’s hello message then
        // x connects vi and vi+2
        add x into R’
    end if
end for
// Now there are one or more candidate vehicles can be selected
Rlt(vi, vi+2) = lt(vi, vi+2)
Vr  vi+2
for each vehicle r in R’ do
    if Rh(vi, vi+2) < min{ lt(vi, r), lt(r, vi+2) } and r  vi+1 then
        Rh(vi, vi+2) = min{ lt(vi, r), lt(r, vi+2) }
```

```
        Vr □ r
    end if
end for
return Vr
```

2.7 MESSAGE FLOW

At the beginning, each vehicle sends a hello message to a BS and the BS sends the HELLO message to the SDNi-MEC server for the connection setup. When the connection is established, the SDNi-MEC server sends back a HELLO message. Then, the communication between vehicle 1 and vehicle 2 begins. When vehicle 1 or 2 reports/transmits its context it is denoted as information the BS sends Packet In to the SDN controller of the SDNi-MEC server. The Packet in triggers the packet sending event to inform the SDN controller of the SDNi-MEC server that a 4G/LTE path is established for data transmission between vehicle 1 and vehicle 2. The lifetime of the V2V path is derived and calculated by the SDN controller of the SDNi-MEC server. In the Open Flow protocol each OpenFlow message has its own effort, e.g., construct, copy, compare, and print. The FlowMod message allows the SDNi-MEC server to modify the states of the BSs, which are equipped with the OpenFlow protocol. In the process of offloading, some deviations may occur such that the V2V path is broken earlier then its originally expected lifetime.

When the V2V path for V2V offloading is disconnected, the peered vehicles switch back to the cellular network. Thereafter, the SDN controller of the SDNi-MEC server tries to find a new V2V path between the peered vehicles for V2V VANET offloading. When the V2V path is broken, the corresponding vehicle sends the repaired message to the SDN controller of the SDNi-MEC server through a BS, which triggers the recovery event. After a repaired V2V path is found, the drive-away vehicle is replaced with the repaired one, which connects the previous vehicle v and the next vehicle v+2. Therefore, the corresponding routing path can be kept. The SDN controller of the SDNi-MEC server sends the FlowMod message to modify the corresponding routing tables of the vehicles.

PacketIn to the SDN controller of the SDNi-MEC server. The PacketIn triggers the packet sending event to inform the SDN controller of the SDNi-MEC server that a 4G/LTE path is established for data transmission between vehicle 1 and vehicle 2. In the OpenFlow protocol, each OpenFlow message has its own effort, e.g., construct, copy, compare, and print.

When a V2V path for V2V VANET offloading is found, the SDN controller of the SDNi-MEC server sends FlowMod to modify the corresponding BS and the BS sends the switch message, which includes the V2V routing path, for modifying the corresponding vehicle routing tables. The SDNi-MEC server collects the reported context from the vehicles and then generates a graph for each pair of peered vehicles that are communicating with each other using the cellular network. The graph denotes the current network topology.

Then, the SDN controller of the SDNi-MEC server executes the proposed LT-NSR algorithm to find a V2V path between the peered vehicles for V2V VANET offloading. When a V2V path for V2V VANET offloading is found, the SDN controller of the SDNi-MEC server sends FlowMod to modify the corresponding BS and the BS sends the switch message, which includes the V2V routing path, for modifying the corresponding vehicle routing tables. Figure, depicts the message flow of disconnecting the V2V path unexpectedly. When the V2V path is broken, the corresponding vehicle sends the repaired message to the SDN controller of the SDNi-MEC server through a BS, which triggers the recovery event. After a repaired V2V path is found, the drive-away vehicle is replaced with the repaired one, which connects the previous vehicle vi and the next vehicle vi+2. Therefore, the corresponding routing path can be kept. The SDN controller of the server sends the FlowMod

message to modify the corresponding routing tables of the vehicles. When the V2V path for V2V offloading is disconnected, the peered vehicles switch back to the cellular network. Thereafter the SDN controller of the SDNi-MEC server tries to find a new V2V path between the peered vehicles for V2V VANET offloading.

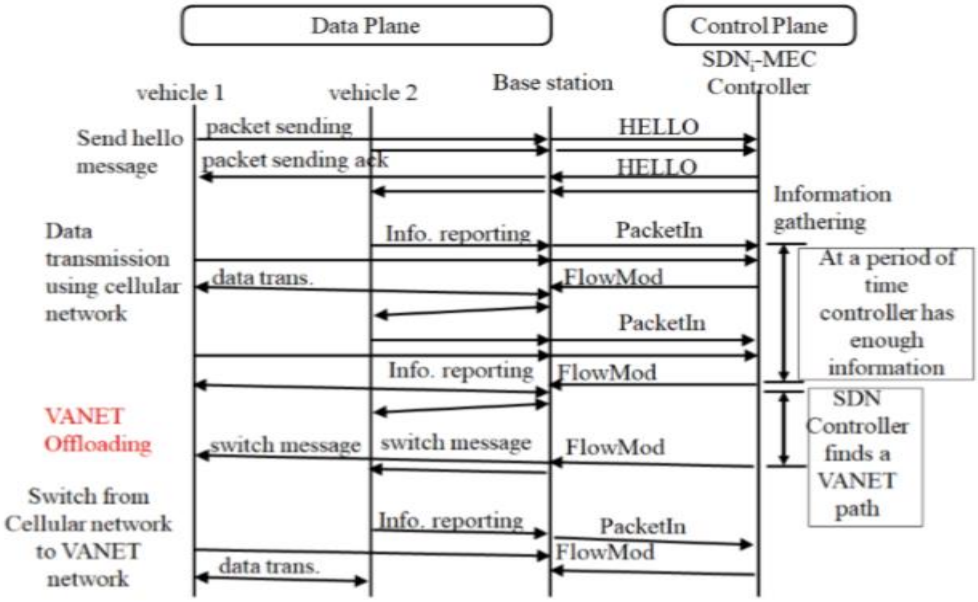

Fig 2.6 Proposed V2V method

After receiving the message, the SDN controller of the SDNi-MEC server sends the FlowMod message back to notify the peered vehicles 1 and 2 to use the cellular network to continue their communication.

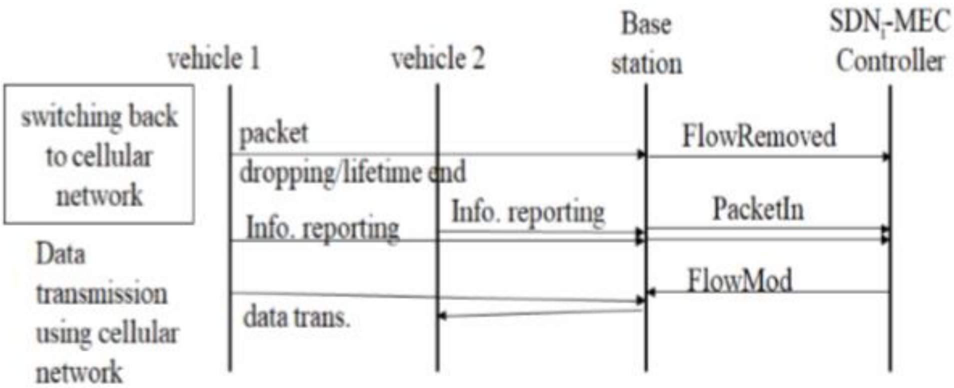

Figure 2.7 The message flow of ending the V2V VANET offloading.

The message flow of disconnecting the V2V path unexpectedly. When the V2V path is broken, the corresponding vehicle sends the repaired message to the SDN controller of the SDNi-MEC server through a BS, which triggers the recovery event.

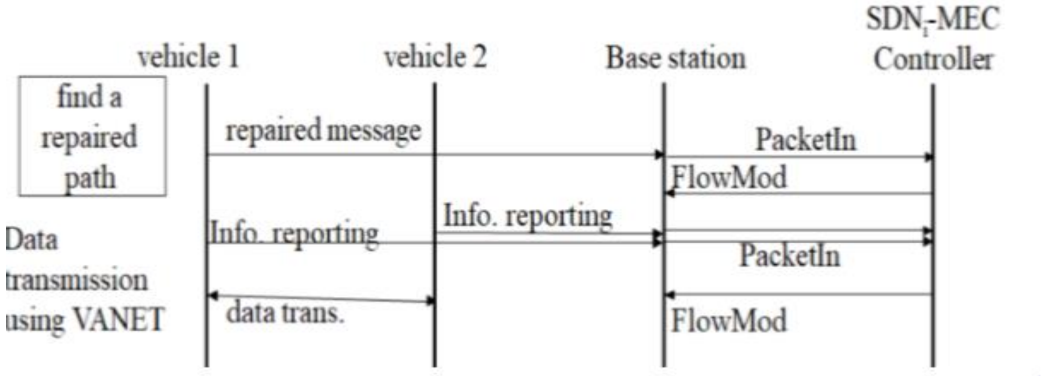

Figure 2.8 The message flow of disconnecting the V2V path unexpectedly.

After a repaired V2V path is found, the drive-away vehicle is replaced with the repaired one, which connects the previous vehicle vi and the next vehicle vi+2. Therefore, the corresponding routing path can be kept. The SDN controller of the SDNi-MEC server sends the FlowMod message to modify the corresponding routing tables of the vehicles. When the V2V path for V2V offloading is disconnected, the peered vehicles switch back to the cellular network. Thereafter, the SDN controller of the SDNi-MEC server tries to find a new V2V path between the peered vehicles for V2V VANET offloading.

2.8 PERFORMANCE ANALYSIS

The NS3 simulator and the VANET-highway mobility model are used to simulate the V2V VANET offloading scenario. This highway mobility model provides realistic movement on highways, which includes the Intelligent Driver Model (IDM) and multi-lane scenarios. With this highway mobility model, one can generate some realistic traffic data, which is taken as input in the proposed method. The simulation was carried out in a 5.0 km × 20.0 m region and Table IV shows the related parameters. When a V2V path for V2V VANET offloading is found, the SDN controller of the SDNi-MEC server sends FlowMod to modify the corresponding BS and the BS sends the switch message, which includes theV2V routing path, for modifying the corresponding vehicle routing tables.

Assuming the OBU in each vehicle has a cellular network interface network interface, let two vehicles s and d be communicating with each other, for which s is the source, and dis the destination. In the process of transmission, packet loss occurs when one or more data packets are delivered across relays. Source s is always able to transmit packets to destination d through the BSs in our highway scenario. Note that the number of vehicles is derived based on the flow which denotes how many vehicles/sec are generated in our highway scenario. In the evaluation, the performance metrics are the offloading fraction, average throughput, average lifetime and delivered data volume of the V2V path:

- Offloading Fraction (%): It denotes the percentage of the V2V VANET offloading of all vehicles.
- Average Lifetime (secs): It denotes the average time length of all V2V paths.
- Delivered Data Volume (MB): It denotes the data volume transmitted using VANET network.
- Average Throughput (Mbps): It denotes the average throughput of all vehicles. The average throughput is calculated based on the average data flow volume that each destination d has received.

2.8.1 THE MOBILITY MODEL

The performance analysis is based on the highway scenario that has different numbers of vehicles at different times. When the traffic is congested on the highway, the speed of each vehicle also decreases. Let Vn denote the total number of vehicles on the highway. Each vehicle moves forward on the highway. At the start of the simulation, the speed of each vehicle is varied from 60 km/h to 120 km/h. obviously, network quality and available bandwidth will become less when vehicle density increases.

In the simulation time, each vehicle starts from a fixed position and then moves from left to right. To simulate a realistic highway scenario, the speed and acceleration should be varied with time. Overtaking and lane changing are also supported.

2.8.2 RESULTS

In this paper, LT-NSR with the path recovery function (LT-PR) is compared with the basic greedy routing (GD-NSR), which takes the minimum hop count to construct the V2V path for transmitting packets. The function of LT-PR is to try to repair/recover the broken V2V path such that the corresponding peered vehicles can still communicate with each other using the VANET network. The LT-PR function can repair a broken V2V path and make it possible for more mobile data to be offloaded continuously. In this part, each link is associated with a constant transmission rate of 2Mbps. Depict the relationships between the numbers of paired vehicles that are communicating with each other and the average throughput in the cellular network and VANET respectively, for which situations of different vehicle densities using the proposed LT-NSR scheme with the path recovery function (LT-PR) are depicted. In the test, links with the cellular network were established when the vehicles were generated and drove on the highway. The average throughput decreases when the number of paired vehicles that are communicating with each other increases. For the low density

situation, Figure 2.8 depicts that the average throughput in the cellular network is reduced as time goes by because the number of paired vehicles that are communicating with each other increases as time goes by, which is shown in the figure.

The V2V paths cannot be established easily because there are not so many vehicles that can be used to construct V2V paths in the situation of low density. An illustrated example is as follows. At around the 130th second, a new cellular networking link is started for a new pair of vehicles that are communicating with each other. 192th second, the corresponding paired vehicles that are communicating with each other switch back to the cellular network and then the average throughput in the cellular network decreases. After a while the other V2V path starts at the 201th second.

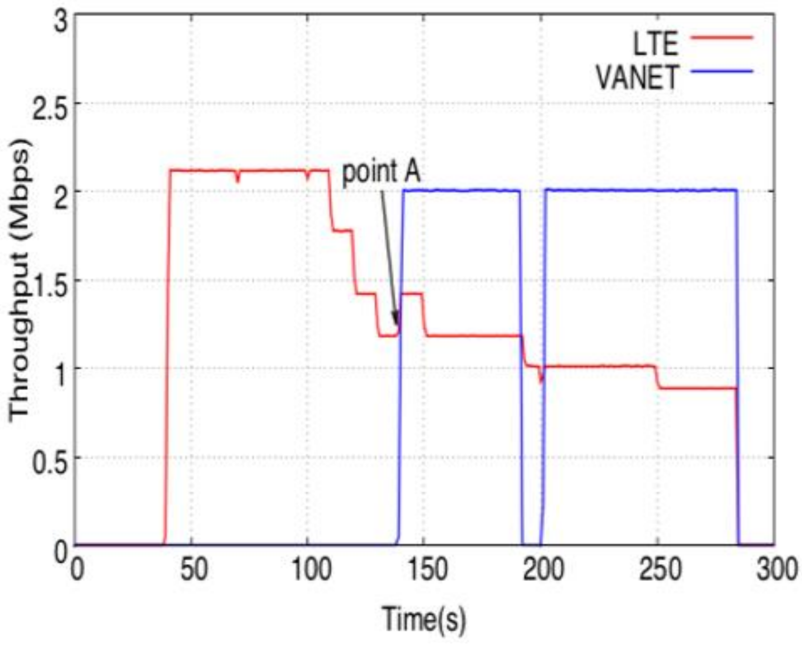

Figure 2.9 Average throughput (fw D 0.07, Vn D 20).

The average throughput in the cellular network declines rapidly and the average throughput in the VANET rises after the 24th second. The reason is much bouncing occurs, which is depicted.

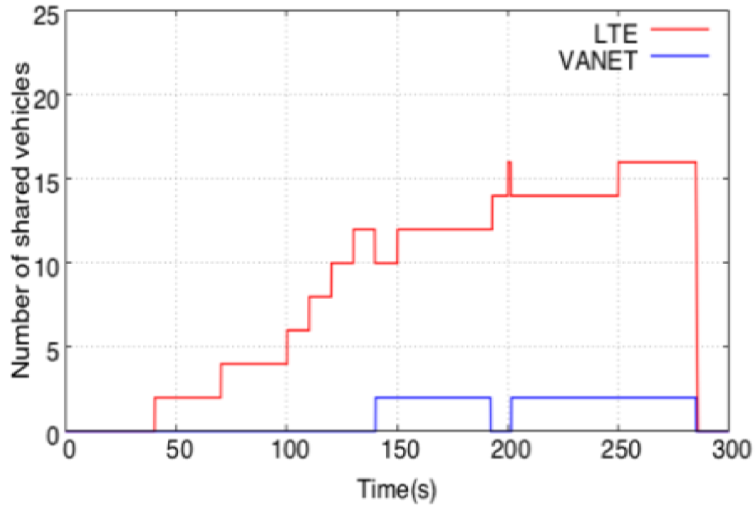

Figure 2.10 Number of vehicles (fw=0.07, Vn D 20).

Even if a V2V path is established using the GD-NSR scheme, the life time of the V2V path is very short and the mobile data can't be offloaded to the VANET network smoothly. The bouncing situation means that many vehicles left the cellular network and switched to the V2V paths for offloading and then switched back to the cellular network again very soon. Therefore, the mobile data cannot be offloaded smoothly and causes some delays.

The average throughput for the cellular networking link that each vehicle can get is much higher than the situation of low density. The reason is as follows. The number of paired vehicles that are communicating with each other in the situation of middle density is higher than in the situation of low density. Thus, compared with the situation of low density, it can find more V2V paths for more paired vehicles. As a result, the average throughput in the cellular networking link becomes higher than that in the situation of low density because more paired vehicles are offloaded to V2V paths. Additionally, the time length of using the V2V offloading in the situation of middle density is much longer than that of the situation of low density because more vehicles are available to become relays and do packet forwarding for the paired vehicles that want to offload to the V2V paths. A V2V path is broken at the 175th second in the situation of middle vehicle density. The proposed LT-PR repairs the broken path rapidly at the 175th second such that the V2V path can be kept. That is, LT-NSR with LT-PR can make the network state more stable.

In the situation of low density, 30.8 MB is offloading using the GD-NSR scheme and the LT-NSR scheme with the recovery function (LT-PR). The delivered data volumes of all peered vehicles that are communicating with each other using these three schemes are the same because there are few V2Vpaths that can exit in the VANET network for all of these three schemes. The reason is that

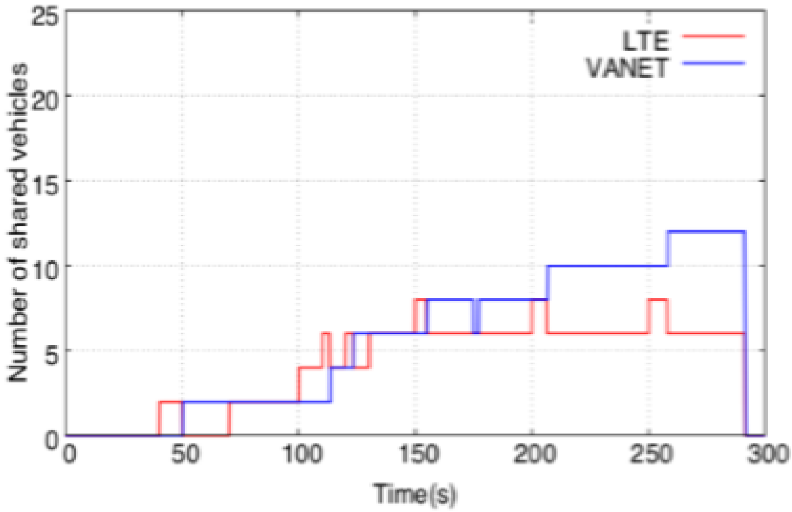

Figure 2.11 Number of vehicles (fw D 0.12, Vn D 35).

each peered vehicle that switches to the V2V path can transmit their data with the maximum transmission rate, i.e., 2 Mbps. Since the offloading situations for the GD-NSR scheme and the LTNSR scheme with LT-PR are the same, the delivered data in VANET are the same for both schemes

In the situation of high density, there are many vehicles that can provide relays and do forwarding. The number of vehicles using VANET increases because of the high probability of finding a V2V path. This results in the average VANET through put decreasing as time goes by, which is depicted in Figure 15-(b). Comparing Figure 12-(b) with the situations of using LT-NSR with LTPR and GD-NSR are similar. This part shows the evaluation of the efficiency of transmission based on the aforementioned traffic patterns. After the V2V paths are established gradually, the maximum delivered data volume rises.

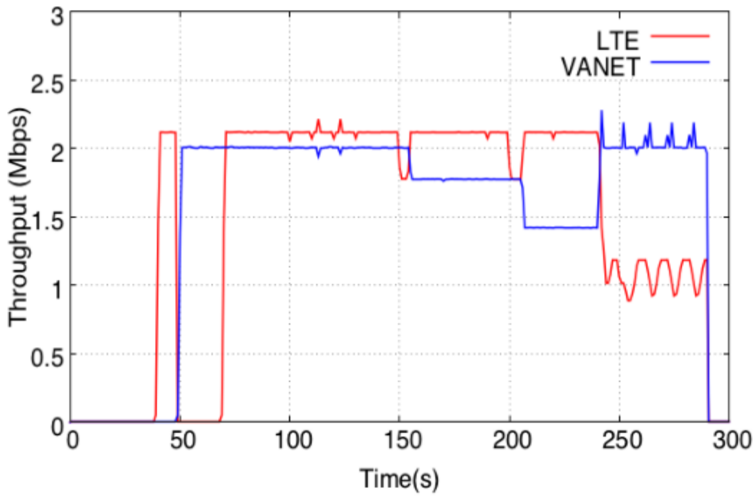

Figure 2.12 Average throughput (fw D 0.12, Vn D 35).

Figure depicts the maximum delivered data volume in the VANET network for different vehicle densities. In this situation, many vehicles can provide relays and do forwarding. The higher probability of finding the V2V path (1) results in fewer vehicles staying in the cellular network because it is much easier to find V2V paths for offloading and (2) brings the low average throughput of the VANET network because more paired vehicles are offloaded to V2V paths. Obviously, the VANET network is congested when most of the vehicles switch from the cellular network to the VANET network. Due to the long lifetime of the V2V paths, which results from the higher vehicle density, a growing number of vehicles keep their V2V routing and share the VANET available bandwidth. This also leads to the average throughput of VANET decreasing as time goes by. A V2V path is broken at the180th second and another one is broken at the 230th second. LT-PR successfully repairs the V2V path and continues the communication using the VANET network after the180th second but the other one can't repair the broken path and the communication path is switched from the VANET network back to the cellular network. On the other hand, when the V2V path is broken at the 230th second, the left vehicle that results in the broken V2V path is the only one that can communicate with both its previous vehicle and its next vehicle. That is, without the left vehicle, LT-PR can't find a supplement vehicle that can repair the broken path.

In the situation of middle density, 128.5MB and 154.5MB are offloaded using the GD-NSR scheme and the LT-NSR scheme with the recovery function (LT-PR), respectively. The delivered data volume using the GD-NSR scheme is lower than that of using the LT-NSR scheme with the recovery function(LT-PR).The reason is that the LT-NSR scheme with the recovery function (LT-PR) repairs the broken V2V path rapidly to continuously keep offloading in the VANET network;

In the situation of low density, only 9.7% of the mobile data can be offloaded for both schemes. In the situation of middle density, the offloading fractions are 45.8% and 58% for GD-NSR and LT-NSR with LT-PR, respectively. The proposed LT-NSR scheme with the recovery function (LT-PR) outperforms the GD-NSR scheme because there are more vehicles that stayed in the VANET network. In the situation of high vehicle density, the offloading fraction is up to 91.6% using the LT-NSR scheme with the recovery function (LT- PR); and the offloading fraction is 91% using the GD-NSR scheme.

The average lifetime of V2V paths can become much higher when the vehicle density increases. For the GD-NSR scheme, the average lifetime of V2V paths is 108, 115 and 121 seconds in the situations of low, middle and high vehicle density, respectively. For the LT-NSR scheme with the recovery function (LT-PR), the average lifetime of V2V paths is 108, 170 and 184 seconds in the situations of low, middle and high vehicle density, respectively.

Offloading fractions of these two schemes are almost the same in the situation of high density. The reason is as follows. Although the average lifetime of each V2V path using the LT-NSR scheme with the recovery function (LT-PR) is longer than the GD-NSR scheme, the V2V paths can be found more easily using the GD-NSR scheme. Thus, the number of V2V paths that can be found using the GD-NSR scheme is more than that of using the LT-NSR scheme with the recovery function (LT-PR) in the situation of high density. It makes the offloading fraction of using the GD-NSR scheme keep up with that of using the LT-NSR scheme with the recovery function (LT-PR).

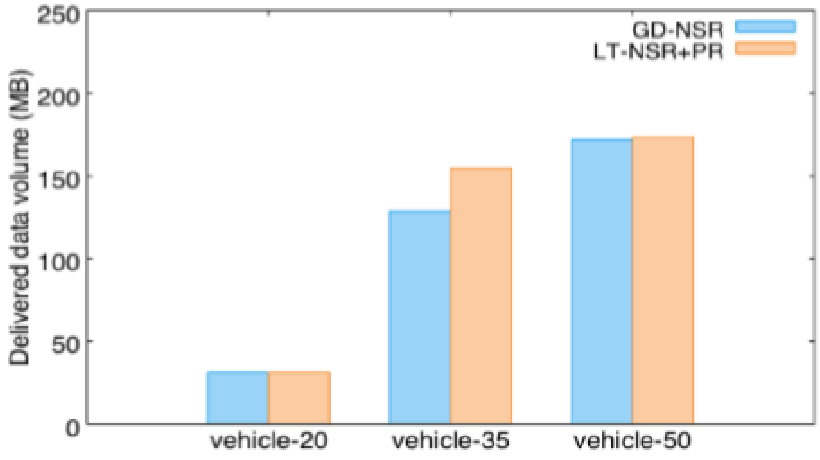

Figure 2.13 Delivered data volume for situations of different densities.

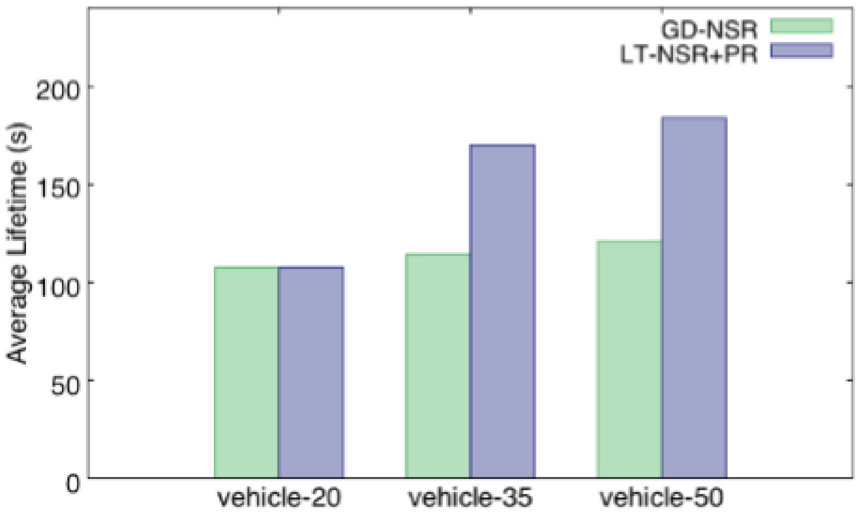

Figure 2.14 Average lifetime of V2V paths for of different vehicle density.

The reason is that even though some V2V paths can be established in the situation of low density, the hop counts and the lifetime of these few V2V paths are almost the same for both schemes. In the situation of middle density and high density, the proposed LT-NSR scheme with the recovery function (LT-PR) tries to find a V2V path that has the maximum lifetime instead of having the minimum hop count.

Additionally, the time length of using the V2V offloading in the situation of middle density is much longer than that of the situation of low density because more vehicles are available to become relays and do packet forwarding for the paired vehicles that want to offload to the V2V paths.

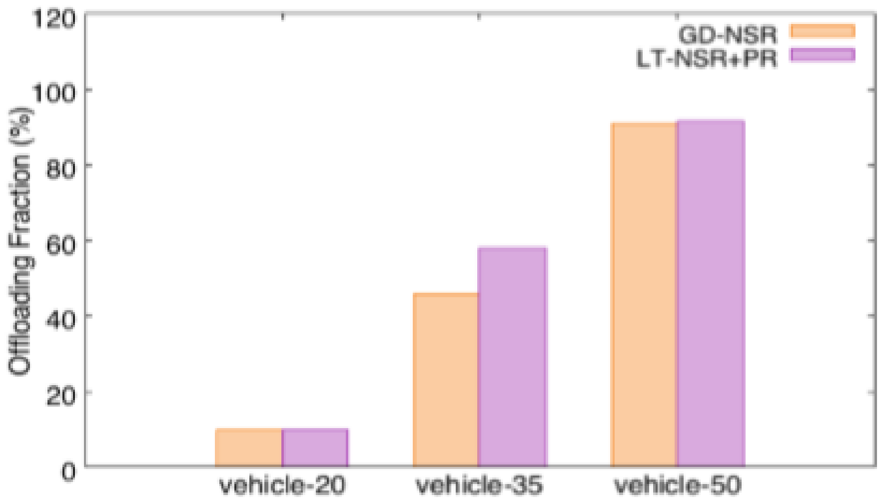

Figure 2.15 Offloading fractions for situations of different vehicle density.

A V2V path is broken at the 175th second in the situation of middle vehicle density. The proposed LT-PR repairs the broken path rapidly at the 175th second such that the V2V path can be kept. That is, LT-NSR with LT-PR can make the network state more stable.

The average throughput decreases when the number of paired vehicles that are communicating with each other increases. For the low density situation, depicts that the average throughput in the cellular network is reduced as time goes by because the number of paired vehicles that are communicating with each other increases as time goes by, which is shown in the Figure 2.10. After a period of time, a V2V path for offloading can be established, which is derived by the SDN controller of the SDNi-MEC server. The V2V path and the average throughput in cellular network increases immediately. The corresponding paired vehicles that are communicating with each other switch back to the cellular network and then the average throughput in the cellular network decreases.

When two vehicles are communicating with each other using cellular network, the data transmission can be offloaded to the V2V path that exists between these two vehicles. These two vehicles switch back to the cellular network to communicate with each other when the corresponding V2Vpath is broken. This paper has proposed the SDNi-MEC architecture such that the calculation of the V2V path for data offloading can be derived using the centralized way in the network edge, instead of having it in a distributed way among vehicles.