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Prediction-based Opportunistic Greedy Routing for Vehicular Ad Hoc Networks

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***Abstract*— In recent years, intelligent transportation systems (ITS) applications e.g. active traffic management, safety application, etc. are gaining popularity. Again internet-based services are also emerging nowadays in vehicular communication networks. Therefore, a suitable routing mechanism is essential to support delay tolerant networking to ensure reliable information exchange. On the other hand, geographical knowledge discovery based on mobility information is another novel approach which has great opportunity to improve existing networking procedures for vehicular communication. In this paper, a Prediction-based Opportunistic Greedy Routing (POGR) algorithm is proposed which utilises mobility data mining to facilitate routing decision in vehicular communications. Hybrid network architecture is considered where both Vehicles-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communications may able to take place. The proposed algorithm follows the IEEE WAVE trial use standards as well as the EU GeoPKDD project deliverables. A detail description of the framework, algorithms and arguments with few illustrations are presented.**

Keywords- mobility data mining; VANET routing; ITS; WAVE

I. INTRODUCTION

In today's world Travel, Transport and Traffic are essential parts of our day-to-day life. Nowadays it is becoming more and more complex to meet the challenges of road traffic management, ensuring safety, security and information availability. Furthermore, with the advancement and popularity of internet-based applications and services, people's motivation of using these are not yet limited to home boundary. Therefore, to support these primary challenges it is essential to have robust and scalable network architecture which can able to provide necessary support to ensure the alignment of our real-life experiences and activities with electronic applications and services within the expectation preserving individual privacy. Vehicular Ad hoc Network (VANET) consists of moving vehicles on roads and highways that are able to communicate with each other as well as with roadside communication infrastructures. It is assumed that the VANET nodes may have Dedicated Short Range Communication (DSRC) enabled device and WLAN/GPRS/WiMAX based communication medium with on-board navigation system. In particular VANET is a special kind of multi-hop wireless ad hoc network technology that is mostly concerned with mobility, frequent network disconnection and highly dynamic topology. To support Intelligent Transportation System (ITS), IEEE is also working with the new technologies e.g. IEEE 1609 Wireless Access in Vehicular Environment (WAVE) standards which aim to support resource management, security services for applications, networking services and multi-channel operations. The IEEE 802.11p standard which is expected to be finalised in November 2010, is aimed to use the 5.9 GHz frequency band, to provide the underlying support in MAC and PHY layer for WAVE technology. The DSRC/WAVE technologies aim to support vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications for ITS [1]. To maintain efficient communication and ensure data dissemination many routing protocols have been proposed in recent years but unfortunately only few have addressed the real-life scenarios, issues, aspects and constrains. This paper proposes a delay tolerant routing approach Prediction-based Opportunistic Greedy Routing (POGR) which uses opportunistic networking based on node movement trajectories and utilises the proactive mobility data mining techniques which predict the neighbouring node's trajectory and greedily forwards information towards the destination. The packets containing the information itself act intelligently on the fly to find opportunistic route to reach the destination. The remainder of the paper is organised as follows: the section II describes the related work, background and motivation of this investigation. In section III, the assumptions and overall network architecture is discussed, Section IV addresses the POGR techniques in details. In section V, the proposed routing algorithm is described with a number of scenarios and illustrations. Finally, section VI brings conclusion and future direction in this research work.

II. BACKGROUND AND RELATED WORKS

High mobility and frequent network disconnection induce primary challenges in VANET architecture. Vehicles on roads and highways always need to follow traffic rules and regulations, lane, signals as well as specific driveway patterns to move within the city centres, busy office areas and so on. And a VANET node thereby continuously generates mobility data (spatial information) based on its movement. This information can be available through onboard communication devices, navigation systems even from passenger's mobile phones. Today's modern traffic management and monitoring systems are also able to detect the movement of vehicles on the road through underlying sensors although that is quite costly and hard to manage. Therefore, the reality is the vehicles

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entering into particular city area or map region in the territory can be tracked and monitored. By applying appropriate data mining techniques, this mobility information can provide certain assumption on how the vehicle may behave in future or near future. The Geographical Privacy Aware Knowledge Discovery and Delivery (GeoPKDD) [2], [3] EU project has established the theory, techniques and methods with real-life experimental results on how to predict the mobility patterns using mobility and traffic data information. Another EU project – Mobility Data Mining and Privacy on the move (MODAP) [4] has recently been started which also aims to continue the efforts started at the GeoPKDD project while their focus is on privacy. The main focus of this paper is to use the mobility prediction on opportunistic routing greedily for VANET.

Anchor-based Street and Traffic Aware Routing (A-STAR) [5] utilises anchor points and traffic information to determine the shortest paths from source to destination. It uses both static and dynamic maps to maintain statistical analysis to discover knowledge about the network. The static map discovers the stable bus routes which implies fixed amount of traffic while the dynamic map is generated based on the real-time traffic generation. Mobility-centric Data Dissemination algorithm for Vehicular network (MDDV) [6] is another position-based routing that uses geographical location information along with trajectory information to provide reliable and efficient routing. It deploys opportunistic networking to forward packets in the vehicle’s mobility-centric approach. It assumes three forwarding approaches – opportunistic, geographical and trajectory-based forwarding. Vehicle Assisted Data Delivery (VADD) [7] routing is specially designed for sparse network. It aims to improve the network disconnection problem using prediction of vehicle mobility which is limited by the traffic pattern and road layout. In every junction point the source node makes its decision to forward packets based on the path that has smallest packet delivery delay. In experiments and simulations, VADD outperforms the existing geographical routing techniques by delay, packet delivery ratio as well as control packet overhead [7]. In [8] a Directional Greedy Routing (DGR) is proposed which forwards packets to the nodes those are moving towards the destination node. An extension of DGR, Predictive DGR (PDGR) is also proposed [8] where current and future predicted mobility information (derived from the traffic pattern and street layout) are used to make decision on how to select the next hop for forwarding packets. A Mobility Pattern Aware Routing Protocol (MPARP), proposed in [9] for heterogeneous vehicular networks (HVN). It utilises the WiMAX base stations (BS) as a location management system and use 802.11 to communicate along the vehicles. When a sender wishes to forward a packet to a destination node it requests a route to the 802.16 BS. WiMAX BS- then predicts the current location of the destination; computes a route for it and replies back to the requester.

III. ASSUMPTIONS AND NETWORK ARCHITECTURE

The proposed network architecture in this paper focuses to maintain the same the protocol stack and operation procedures described by the IEEE WAVE trial standards. In Fig. 1 shows the proposed network architecture. RSU will offer the predictive mobility pattern information through specific service applications within the persistent WBSS mode. Vehicles that pass through the RSU are able to join in the WBSS and utilise the announced application service to enhance their routing with 1-hop neighbours’ predictive mobility pattern information. OBUs send neighbour node’s mobility pattern information through service channels to RSU with a specific service provider id (SPID) by which the RSU will distinguish the individual service request and forwards them to a central knowledge base e.g. Vehicle Information Management (VIM) systems (Fig. 1). The mobility information sent by the OBU will store in the database for each information message exchange with the RSU. A mobility data mining model is assumed to be available to produce predictive mobility information based on vehicle’s mobility history information and current location. The computational and processing times are subject to theoretical and experimental evaluation. Based on the prediction, the OBU will make decision to forward packets greedily to the node which is selected as the best forwarding node. The node with the highest prediction to travel towards the destination node is selected as the forwarding node. Each OBU will store a copy of the predictive mobility information in its log files and will use it in the without-WBSS operation.

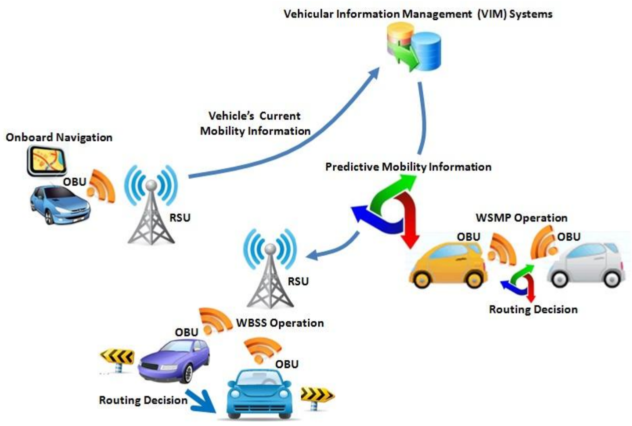

Figure 1. Proposed network architecture of the predictive routing for vehicular communication

In without-WBSS mode operation, OBUs in the vehicles can directly communicate with each other to share their own predictive mobility patterns through WSMPs only in the absence of a RSU. In this mode, the OBUs switches back and forth as the service “provider” and “user” role to exchange messages and their current related mobility information. So, nodes will facilitate with minimum information required to forward the data packets and make on-demand routing decision. This approach follows the basic general VANET networking concept. As mentioned earlier, every OBU communicates with the centralised data mining service through RSU and at the same time caches its own predictive mobility patterns in log files. The vehicular node periodically updates this information whenever it is within the range of a RSU. Only if the OBUs are out of communication with a RSU for a certain period of time and want to communicate with another vehicular node or need to forward data packets as an intermediate node, they will enter into the without-WBSS mode of operation. Every OBU is assumed to have a small mobility miner in the onboard computational processor. On-board mobility miners utilise the mobility logs to generate trajectory predictions for individual mobile nodes and will only be activated in times of WSMP based operation as shown in Fig. 1. Based on the mobility patterns of its neighbours as well as its own trajectory prediction, the node will either decide to forward the packets greedily to any of the selected 1-hop neighbour which is predicted to move closely with the destination node. If no such forwarding node is found, the sender OBU will wait for a better opportunity deploying opportunistic approach of carry and forward data packets. The VIM System is a composition of data collection, data warehousing and data mining tools. RSU will be connected to the VIM system through application level interfaces defined by the IEEE WAVE protocols. In this model, the geographical mobility data mining techniques described in GeoPKDD Project [2] can be used. The aim of this project was to develop theory, architecture and applications for spatio-temporal knowledge discovery as well as data warehousing and data mining techniques for moving object's trajectories. The project published several project deliverables like trajectory data management and ensuring privacy, spatio-temporal data mining, a framework for progressive movement data mining and visualisation techniques and few demonstrations e.g. transportation management and mobile outdoor recreation [10]-[13]. GeoPKDD mobility miner architecture can be used in order to query and collect the vehicle mobility information on-demand as well as to utilise mobility data mining to predict vehicle's mobility patterns for opportunistic and delay tolerant networking services. Interesting readers can be referred to the GeoPKDD project website [4] for further information.

IV. PREDICTION-BASED OPPORTUNISTIC GREEDY ROUTING

A. Predictive Mobility Information Query and Retrival

When an OBU wants to send data packets to one or more destination node it searches for any nearby RSU. If a RSU is found within the direct communication range of the OBU, it queries the mobility data mining engine and retrieves the predictive mobility information of the neighbouring nodes. The initial query includes the predictive mobility information for source (or intermediate), destination and all of its 1-hop symmetric neighbour nodes for particular time intervals. In the absence of a RSU, the requesting node will broadcast this request message to all of its 1-hop symmetric neighbours. If any 1-hop neighbour has direct connectivity with any RSU, it forwards the request to the RSU. The corresponding RSU then retrieves the query result from the VIM systems and forwards back to the source node through neighbour node. In other case, if the neighbour node does not have any connectivity with any RSU but it has information about the destination node's mobility, then it will forward this information along with its own mobility data to the requested source node. Otherwise, the neighbour node just ignores the broadcast request. In every step of the routing process, the algorithm tries to get the updated information about the destination's current mobility which is appended to the packet header later on. Depending on the network condition, the requester node itself determines the number of interval periods (N_{IP}), an integer, for which it will try to retrieve the predictive mobility information. Short time intervals will give more accurate prediction but at the same time will increase the processing and computational load as well as control packet overhead. On the other hand, larger time intervals will give less accurate information while keep the system load and control packet generation at a tolerable level. Therefore, determining an optimal value of N_{IP} is another challenging issue. The algorithm also sets an initial matching threshold value (M_{Th}) which determines how much confidence and support will be necessary to choose a best forwarding node which will ensure optimal mobility prediction to match with the destination node.

B. POGR Algorithm: Pseudo Code for OBU

Initially the value of N_{IP} will be set to 1 i.e. the requester node will only request for 1 interval of prediction. The larger the value of N_{IP}, the more accurate prediction the system will have. In the United Kingdom the standard speed limits are 30, 40, 50, 60 and 70 mph. In this proposed architecture it is assumed that vehicles will update their location data through GPS in every 15 metres as usual GPS receivers without WAAS (Wide Area Augmentation System) technology are accurate within 15 metres of region on average [14]. The time required to travel 15 metres at the speeds of 30, 50 and 70 mph are 1.118, 0.671 and 0.479 seconds, respectively which can be set as the value of the time interval. The trajectory confidence level shows how closely a neighbour's trajectory follows destination node's trajectory. It depends on the geometric shapes, travelled distance (e.g., length of the trajectory in space), duration of the trajectory in time, movement vector etc. An 80-100% confidence levels are used to initialise M_{Th}. Although sufficient practical and theoretical analysis is need to set an optimal value of M_{Th}. Algorithm I will retrieve the current mobility information and predictive trajectories of all the 1-hop neighbour nodes and destination while algorithm II will sort and select the optimal forwarding node which meets the matching threshold value.

The algorithms are as follows:

Algorithm I: Predictive Trajectory Information Query (N_{IP}, Node ID)

Notations: 1-hop Neighbours (N), Destination (D)

```
NIP $\leftarrow$ 1 (Number of Interval Periods for which a query has been made)
if an OBU has direct connectivity with a RSU then
    send Query_Request (NIP, Node ID- N, D)
    return (Current Mobility Information, Predictive Movement Trajectories- N, D)
else
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    broadcast Query_Request (NIP, Node ID-N, D) to all 1-hop symmetric neighbours
    if any 1-hop neighbour has direct connectivity with a RSU
        forwards Query_Request (NIP, Node ID- N, D) to RSU
        Query_Request (NIP, Node ID-N) from RSU
        return (Current Mobility Information, Predictive Movement Trajectories- N, D)
    else if any 1-hop neighbour has direct connectivity with the destination node
        forwards Query_Request (NIP, Node ID-D) to destination node
        retrieves Query_Request (NIP, Node ID-N) from neighbour's mobility logs
        return (Current Mobility Information, Predictive Movement Trajectories-N, D)
    else
        retrieves Query_Request (NIP, Node ID-N) from neighbour's mobility logs
        return (Current Mobility Information, Predictive Movement Trajectory-N)
    end if
end if
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Algorithm II: Optimal Forwarding Node Selection (MTh, 1-hop Neighbour List with Trajectories)

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MTh ← value of Matching Threshold to justify the confidence level between different trajectories
Neighbour List ← Sort based on predictive trajectories that best match the destination's one
select the neighbour which has matching level >= MTh in the sorted list as the best forwarding node
if more than one neighbours are found choose the one with minimum packet delivery latency
else
    carry the data packets for a random period then call Algorithm I
end if
```

V. ILLUSTRATION OF POGR ALGORITHM

1) Scenario-1

In Fig. 2, at time T1 node 'A' (source) wants to send a packet 'P1' to one of its multi-hop neighbour node 'C' (destination). Therefore, Node 'A' searches for any nearby RSU and finds RSU-1 within its direct communication range. Node 'A' requests RSU-1 to provide the predictive mobility information for node 'A' (source), 'C' (destination) and all its 1-hop neighbours (node 'B' and others). Node A also mentions in the request that it wants the information for two time-interval periods (T1-T2 and T2-T3). RSU-1 replies with the requested information to node A (Table I). Explain here what PA1, PA2 and PA3 mean. Node 'A' sorts the 1-hop neighbour list according to best match with the destination node's predictive mobility and chooses node 'B' as the next node. According to this choice, 'A' appends the destination node's predictive mobility information into the packet header and greedily forwards packet 'P1' to 'B' at time T1.

Upon receiving the packet 'P1', node 'B' discovers that the destination node for 'P1' is not its 1-hop neighbour. Therefore, at time T2 it searches for nearby RSU to query all 1-hop neighbours as well as update destination node's predictive mobility information. RSU-2 provides the necessary information to 'B' upon its request (Table II). Node 'B' discovers that the predictive mobility of destination node 'C' is changed from (C, T3, P_C3) to (C, T3, $P_{C*}3$). Therefore to ensure successful packet delivery 'B' decides to forward the packet as quick as possible to another node which mobility prediction is closely matched with the destination.

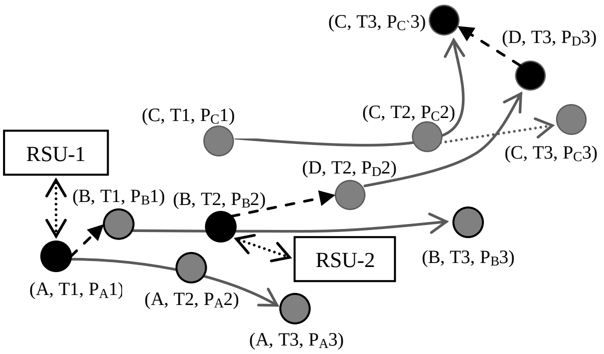

Figure 2. Illustration of Prediction-based Opportunistic Greedy Routing (POGR) algorithm (Scenario-1)

TABLE I. PREDICTIVE MOBILITY INFORMATION RETRIEVED BY NODE 'A' AT TIME T1 FOR SCENARIO-1

ID	Time Intervals	Predictive Mobility	Type
A	T1-T2, T2-T3	(A, T1, P_A1)→ (A, T2, P_A2) → (A, T3, P_A3)	Source
C	T1-T2, T2-T3	(C, T1, P_C1)→ (C, T2, P_C2) → (C, T3, P_C3)	Destination (Initial)
B	T1-T2, T2-T3	(B, T1, P_B1)→ (B, T2, P_B2) → (B, T3, P_B3)	1-hop Neighbour
…	T1-T2, T2-T3	…	Other 1-hop Neighbour

TABLE II. PREDICTIVE MOBILITY INFORMATION RETRIEVED BY NODE B AT TIME T2 FOR SCENARIO-1

ID	Time Intervals	Predictive Mobility	Type
B	T2-T3	(B, T2, P_B2) → (B, T3, P_B3)	Forwarding Node
C	T2-T3	(C, T2, P_C2) → (C, T3, $P_{C`}3$)	Destination (Updated)
D	T2-T3	(D, T2, P_D2)→ (D, T3, P_D3)	1-hop Neighbour
…	T2-T3	…	Other 1-hop Neighbour

Node ‘B’ thus updates the destination node’s prediction information resides in the packet header. Then it sorts its 1-hop neighbour list according to the match with the updated destination node’s predictive mobility information. Node ‘D’ is chosen as the next forwarding node and packet ‘P1’ is greedily forwarded to it. It can be noted that, at time T2 ‘B’ only request the prediction for time interval T2-T3. This is because, it was previously predicted that at time T3 node ‘B’ will move very close to node ‘C’ therefore only a single time interval prediction of mobility is assumed to be sufficient to forward the packet. Now node ‘D’ is able to reach the destination node ‘C’ at time T2 as it is not within the direct communication range. ‘D’ waits T2-T3 time interval and at time T3 it discovers the destination node ‘C’ as its 1-hop neighbour. Then ‘D’ forwards the packet ‘P1’ to its target destination node ‘C’.

2) *Scenario-2*

Scenario-2 is much similar to scenario-1 with only the absence of RSU-2 (Fig. 3). Therefore, at time T2 node ‘B’ searches for any nearby RSU and fails to discover one. At this moment, ‘B’ broadcasts a mobility prediction request (the individual 1-hop neighbours only) message and waits for replies. The message also contains the indication that if any 1-hop neighbour of node ‘B’ has direct connectivity with any nearby RSU or the destination node itself. If a RSU is found then the 1-hop neighbour should forward an update mobility prediction request for the destination node ‘C’. In other case, if the destination node itself is a symmetric 1-hop neighbour of any of the 1-hop neighbour of node ‘B’ then the packet should directly forwarded to the selected node. Unfortunately none cases are satisfied in this scenario. Therefore, upon receiving the mobility prediction from node ‘D’ and others (Table III), node ‘B’ discovers that ‘D’ will be in a more closer position (D, T3, P_D3) than ‘C’ at time T3 (C, T3, P_C3).

But, node ‘B’ is unaware that the destination node ‘C’s predictive mobility has changed at time T2 from (C, T3, P_C3) to (C, T3, P_{C*}3). As node ‘B’ is unable to get the updated mobility prediction for the destination node ‘C’ at time T2 it depends on the locally available data and greedily forwards packet ‘P1’ to node ‘D’. At time T3, node ‘D’ forwards packet ‘P1’ to its destination while it discovers node ‘C’ within its direct communication range.

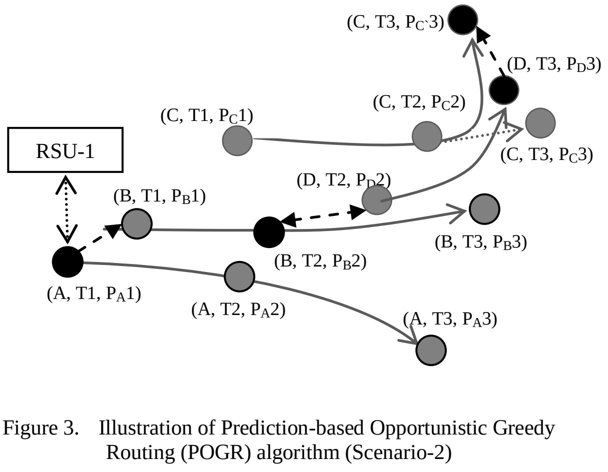

Figure 3. Illustration of Prediction-based Opportunistic Greedy Routing (POGR) algorithm (Scenario-2)

TABLE III. PREDICTIVE MOBILITY INFORMATION RETRIEVED BY NODE ‘B’ AT TIME T2 FOR SCENARIO-2

ID	**Time Intervals**	**Predictive Mobility**	**Type**
B	T2-T3	(B, T2, P_B2) → (B, T3, P_B3)	Forwarding Node
C	T2-T3	(C, T2, P_C2) → (C, T3, P_C3)	Destination (Not Updated)
D	T2-T3	(D, T2, P_D2)→ (D, T3, P_D3)	1-hop Neighbour
…	T2-T3	…	Other 1-hop Neighbour

3) *Scenario-3*

Scenario-3 shown in Fig. 4 is also similar to that described in scenario-2 except the absence of node ‘D’ at time T2. In this scenario, node ‘B’ searches for nearby RSU at time T2 and fails to discover any. Then node ‘B’ broadcasts a mobility prediction request message to all of its 1-hop neighbours. But unfortunately, node ‘B’ is not able to determine any close relation between any of its 1-hop neighbour’s predictive mobility patterns with the destination node’s one. It can be recalled that, ‘B’ identifies the destination node’s predictive mobility information from packet ‘P1’s header which is appended by node ‘A’ at time T1. Therefore, ‘B’ is not able to get the updated information about destination node’s current mobility. So, node ‘B’ decides to wait-and-forward thus deploying an opportunistic strategy.

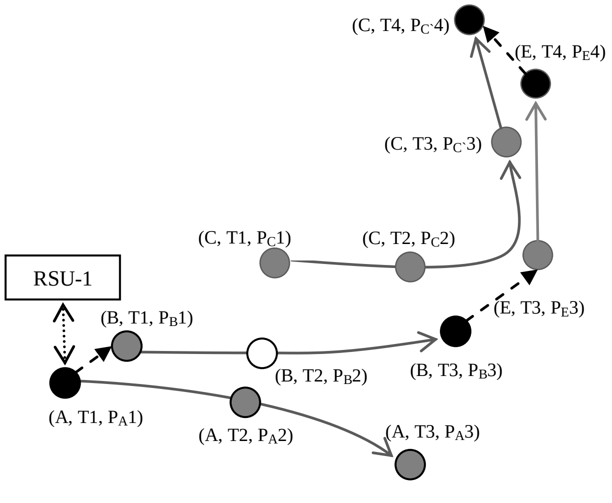

Figure 4. Illustration of Prediction-based Opportunistic Greedy Routing (POGR) algorithm (Scenario-3)

TABLE IV. PREDICTIVE MOBILITY INFORMATION RETRIEVED BY NODE ‘B’ AT TIME T3 FOR SCENARIO-3

ID	**Time Intervals**	**Predictive Mobility**	**Type**
B	T3-T4	…	Forwarding Node
C	T3-T4	(C, T3, $P_{C'}$3) → (C, T4, $P_{C'}$4)	Destination (Updated, 1-hop neighbour of ‘E’)
E	T3-T4	(E, T3, P_E3)→ (E, T4, P_E4)	1-hop Neighbour
…	T3-T4	…	Other 1-hop Neighbour

At time T3, when node ‘B’ reaches at position P_B3, it expects to see destination node ‘C’ within its direct communication (as it is predicted at time T1). But, the intermediate forwarding node ‘B’ is not able to update the mobility information of destination node ‘C’ within the time interval T1-T2 and T2-T3. Therefore, node ‘B’ was unaware about the mobility change happened at time T2. Now, node ‘B’ will again broadcast the mobility prediction request message to all of its 1-hop neighbours. Upon receiving the replies, ‘B’ chooses node ‘E’ which is a 1-hop neighbour of destination node ‘C’ (Table IV). Thus node ‘E’ replies to node ‘B’ with the updated predictive mobility information of node ‘C’. Node ‘B’ appends this information into the packet header of ‘P1’ and forwards it to ‘E’. Node ‘E’ eventually forwards packet ‘P1’ to its ultimate destination at time T4.

VI. CONCLUSION AND FUTURE WORK

In this paper, a novel routing approach is discussed which is best applicable for vehicular communication system in compliance with ITS and IEEE WAVE standards. It can also be considered as a generic approach for delay tolerant opportunistic routing in any type of communication systems e.g. telecommunication networks, wireless sensor and mesh networks or even pure general purpose mobile ad hoc networks. The networking architecture, components, operation procedures and algorithms of POGR are presented in this paper. Nowadays due to the wide deployment of traffic management and vehicle safety applications and services by transportation and law enforcement agencies, it is convenient to have information base like the Vehicle Information Management (VIM) systems discussed above. In that case, vehicular networking architecture can able to evolve a lot utilising mobility data mining information not only in ITS applications but also internet-based on-demand services and multimedia applications. Our future work will direct to the detail theoretical and mathematical modelling of the approach and simulation using realistic vehicular traces.

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