User-oriented cluster-based solution for multimedia content delivery over VANETs

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***Abstract*— Vehicular ad-hoc network (VANET)-based multimedia applications are considered to play a very important role in the future of intelligent transportation systems and vehicular infotainment systems. Socio-economic issues are identified among the main challenges in VANET-based multimedia applications. In response to these challenges, this paper proposes a novel user-oriented cluster-based multimedia delivery solution over VANETs that is able to address vehicle passenger preferences and deliver multimedia content of their interest. Such a solution will support various value added services in the vehicles, e.g. touristic video guide, news, entertainment, etc. In this paper the architecture of the proposed solution is presented together with the cluster-based mechanism employed for multimedia transmissions and the cluster head selection algorithm required for delivery infrastructure management. Simulation-based testing demonstrate how this solution increases system stability resulting in a longer life of the elected cluster head compared to the classic Lowest-ID cluster head algorithm, fact that positively influences the quality of the multimedia transmission.**

Keywords-component; multimedia, quality, vehicular networks

I. INTRODUCTION

Many research efforts in the area of vehicular ad-hoc networks (VANET) try to improve the safety and efficiency of the transportation systems. Lately the focus in this research space moved also towards VANET infotainment applications that aim to increase user satisfaction in traffic. VANET-based multimedia applications are considered to play a very important role in the future of vehicular infotainment and intelligent transportation systems. They may contribute to traffic safety and efficiency by providing detailed information about accidents that will help in the intervention of emergency services and will allow the drivers to predict the duration of the traffic jam in various areas [1]. However, due to great challenges imposed in multimedia transmissions by the high mobility of the vehicles and network instability and scalability, there are only a few multimedia delivery approaches proposed in VANETs.

Socio-economic issues are identified among the main challenges of VANET [2]. The problems include the cost of infrastructure needed for the deployment of VANET solutions and the market penetration of car-to-car and car-to-infrastructure communication technologies. Two solutions were proposed for the latter problem that either enforce a regulative order, or deploy attractive applications in order to advertise the added value of the technology [2]. A user-oriented solution that takes into account passenger preferences is considered an attractive application. In consequence, cost-effective and user-oriented solutions, address these socio-economic challenges. The use of clustering techniques is generally acknowledged to lead to cost-effective infrastructure and energy efficiency solutions [5].

In this context, this paper proposes **a novel user-oriented cluster-based solution for multimedia delivery over VANETs** that is able to personalize multimedia content and its delivery based on the preferences of the passengers and their profiles. The proposed solution includes two algorithms, which focus on cluster formation and cluster head selection, respectively. The cluster formation algorithm aims to group vehicles based on vehicle characteristics and user interest in content. The cluster head selection algorithm makes sure that cluster head function is efficiently distributed among vehicles. The focus in this paper is on the cluster head selection algorithm. Among user interests, both algorithms take into account the velocity of the mobiles, direction of travel and position of the vehicles.

The proposed solution supports the provision of various value added services in the vehicles. One may drive in the area usually visited for shopping and the on-board computer starts playing some videos with the current offers or discounts of the shops in the area. This may be considered a very good support in managing the time and money spent on shopping. Imagine a group of friends visiting a city by car and when they drive around a touristic area the proposed solution will act as a live touristic guide playing video previews of the touristic attractions in that area.

This paper is structured as follows. Section II describes the principle behind the proposed solution and its architecture. Section III details the system architecture and section IV describes the cluster head selection algorithm. Section V presents and analyses testing results and at the end the paper conclusions are drawn.

II. RELATED WORK

In the literature, there are only few proposals of multimedia applications over VANETs. The main identified reason is the great challenges imposed in multimedia transmission by the high mobility of the vehicles and network instability and scalability [6]. In [7] and [8], network coding was employed to address these challenges based on its good performance results in video streaming in large scale systems outside VANET area [9]. In [7], CodePlay, a live multimedia streaming solution was designed based on a recent network coding technique, symbol-level network coding. The solution proposed in [8] uses for multimedia dissemination an approach that combines network coding with a multi-path technique. The possible paths are ranked according to their stability and the layers from the scalable video coding are assigned to these paths in a direct proportionality between the rank of the path and the importance of the layer.

In [10], the challenges mentioned were addressed by an architecture that incorporates two sub-systems, each representing the response to one part of the problem. The first sub-system, a video source trigger, addresses the high mobility issues by implementing a signaling mechanism that continuously triggers video sources to send video data back to receivers. The second sub-system, a video data transfer, addresses the scalability and stability issues by employing a store-carry-and-forward approach for transmitting video data in a partition network environment.

A well-known solution to scalability, stability and mobility issues is clustering. Clustering was successfully applied in mobile ad-hoc networks (MANET) to provide approaches that offer good performances in the presence of these issues [5]. This was an important aspect taken into consideration by the authors when proposing the clustered-based multimedia content delivery over VANETs. In addition, the clustering solution allows for interest-based grouping.

III. Multimedia Solution System Architecture and User-oriented Cluster-based Multimedia Delivery Scheme

The proposed solution uses a client-server architecture based on a hybrid vehicular communication network model, illustrated in Figure 1. The architecture includes a server in the back-end, roadside units (RSU) and the vehicles as clients.

The application server stores the multimedia content. A multimedia content management system like the one proposed in [17] is deployed on the server. This system is able to retrieve the multimedia content based on preference and location information.

The vehicles are organized in clusters based on the user interest in multimedia content, location, direction of travel and velocity. Each cluster is designed to be a k-hop cluster, where k is not greater than 9 as suggested in [11]. Each cluster has a cluster head (CH) and deals with multimedia content according to the user preferences in the cluster. CH is the only cluster node that communicates directly to RSU; the other nodes communicate with the RSU in single or multiple hops via CH. CH sends the cluster user interest and location and other cluster-related information to the server via RSU and receives multimedia content from the server via RSU.

CH further disseminates the multimedia content to all the cluster members. Multimedia communication within each cluster does not use the client-server architecture, extending instead the principle behind the Observer design pattern from the Software Engineering area. Each cluster node holds a list with the same-direction neighbors that were registered during cluster formation process. When the multimedia transmission is initiated by the CH, each cluster node will disseminate the multimedia content to all its neighbors.

The proposed architecture is cost-effective as it is scalable to any number of RSUs available, including relatively sparse VANETs. This is due to the fact that the cluster-based communication is independent from RSU and enables enlarging the transmission range using multi-hop. In addition, RSUs communicate with CHs only, resulting in energy saving at RSU level. Energy efficiency can be further enhanced by employing a sleeping scheme at RSU as presented in [16].

Multimedia delivery is performed using the state-of-the-art Quality Oriented Adaptive Scheme (QOAS) proposed in [12], solution which was already shown to enable high quality in hybrid vehicular communications-based systems [13].

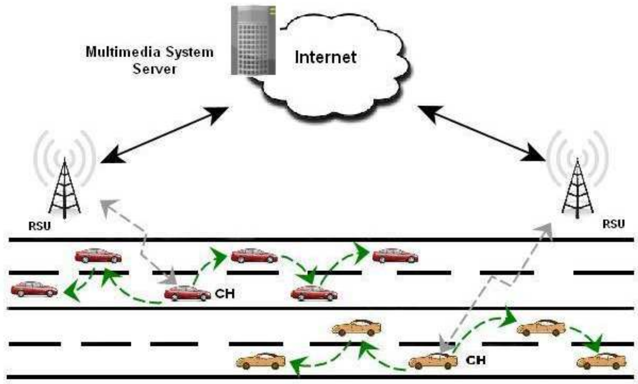

Figure 1. Architecture for the User-oriented Cluster-based Solution for Multimedia Content Delivery

In the proposed network model, both vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) communications make use of the IEEE 802.11p standard that was designed for dedicated short range communication in high-speed vehicular environments [14]. This standard has allocated 7 channels, out of which 6 service channels and one control channel. The control channel is used in the proposed approach for exchanging clustering specific messages and the service channels are used for delivering multimedia data. It is assumed that each vehicle is equipped with multi-channel on board units (OBU) so that IEEE 802.11p-based communications can take place. This dual control-data communication channel design is very important for multimedia transmissions as this is not interrupted by any control.

Specific to our proposed solution, on each vehicle on board unit, a context aware user model framework [4] is deployed, that is able to build the user profile and based on this, to provide recommendations regarding user preferences. These recommendations are in form of a vector of user interests. Consequently each vehicle *k* has associated a vector of interests $R_{ki} = (p_{k1}, p_{k2}, \ldots, p_{ks}, \ldots p_{kn})$, where p_{ki} represents a value, expressed as percentage, which indicates how much the user is interested in topic *i*. Additionally, each vehicle has a location-aware mechanism (e.g. GPS) which supplies information to

OBU, which determines vehicle speed, direction of travel and location.

IV. CLUSTER HEAD SELECTION ALGORITHM

The cluster head selection algorithm uses a three layer-based approach. At the first layer, each vehicle establishes its neighbors that travel in the same direction, computes and retains in a list each neighbor-related information as a 5-tuple composed of (*vehicle id, speed, location, vector of interests, interest compatibility (IC)*). The information of speed, location and vector of interests is periodically broadcasted through "hello" messages by vehicles. Each vehicle is being assigned a unique id (i.e. *vehicle id*) that is used for its identification in the network. IC is computed using cosine similarity metric between the tuples represented by the user interests from the current vehicle and each of its neighbors. The IC between vehicle *x* and *y* is computed as in equation (1).

$$IC_{x,y} = \Phi(x,y) = \frac{\sum_{k=1}^{n} p_{xk} p_{yk}}{\sqrt{\sum_{k=1}^{n} p_{xk}^2 \ \sum_{k=1}^{n} p_{yk}^2}} \qquad (1)$$

At the second layer, for each cluster the cluster head eligibility (CHE) is computed for each node. For CHE computation, a Utility Function-based approach is employed, subscribing the proposed clustering algorithm to the category of Utility Function-based clustering algorithms [15]. The proposed Utility Function takes into consideration vehicle-specific characteristics (e.g. velocity, location) and user interests. It is based on three parameters: average distance (AD), average velocity (AV) and average compatibility (AC) that are further detailed.

In equation (2), it is illustrated how the defined Utility Function is used in the computation of CHE of vehicle *k*. The other terms are described by equations (3), (4) and (5). N_k represents the number of the same-direction neighbors of vehicle *k* (i.e. the length the 5-tuples list of vehicle *k*). In (2), w_1, w_2 and w_3 are weights and their sum is 1.

$$CHE_k = w_1 AC_k + w_2\, AD_k + w_3\, AV_k \qquad (2)$$

AD_k represents the overall average absolute distance between vehicle *k* and the neighbors from the 5-tuples list of vehicle *k* maintained at the first layer as indicated before.

$$AD_k = \frac{\sum_j \sqrt{(x_j - x_k)^2 + (y_j - y_k)^2}}{N_k \times d_{max}} \qquad (3)$$

where (x_k, y_k), (x_j, y_j) are the coordinates of the positions of vehicles *k* and *j* respectively and *j* takes the value of each id from the 5-tuples list; d_{max} represents the maximum value of the transmission distance.

AV_k is the average of the differences between the velocity of the vehicle *k* and those of the neighbors from the 5-tuples list of vehicle *k*.

$$AV_k = \frac{\sum_j |v_k - v_j|}{N_k \times v_{max}} \qquad (4)$$

where v_k, v_j represents the velocity of vehicle *k*, and vehicle *j*, respectively and *j* takes the value of each id from the 5-tuples list; v_{max} represents the value of the maximum speed allowed by the road regulations.

CA_k is the average of the interest compatibilities computed for vehicle *k* and each of its neighbors from the 5-tuples list.

$$CA_k = \frac{\sum_j IC_j}{N_k} \qquad (5)$$

where *j* takes the value of each id from the 5-tuples list.

The CHE_k information is carried by the "hello" messages exchanged by vehicles.

At the third layer, the vehicle with the greatest CHE is selected as cluster head and maintains a cluster membership table that contains all the ids of the vehicles from the cluster. The topic with the highest user interest within the vehicles of each cluster is selected as the interest of the cluster. The CH is informed about this and together with its node id is periodically broadcasted in the network.

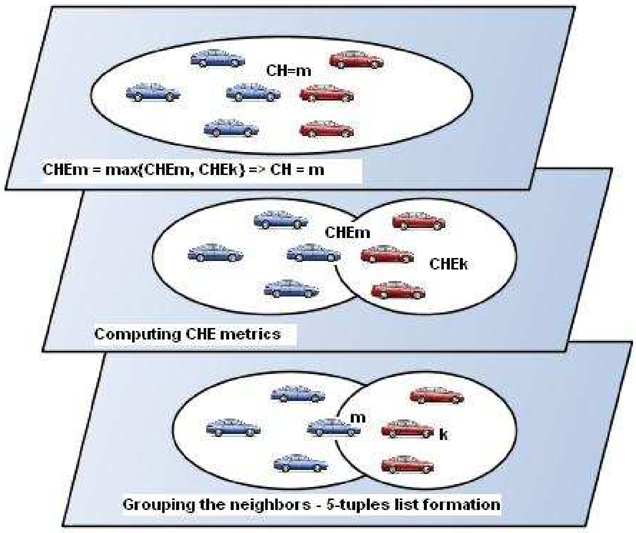

Figure 2. Bottom-up Layered Process of Cluster Head Selection Algorithm

V. TESTING RESULTS

To test the performance of the cluster-head selection algorithm in the context of the multimedia solution proposed, iTETRIS [18], a vehicular simulation platform, was employed. This simulation platform integrates SUMO, a traffic simulator, and NS-3, a network simulator.

Delivering multimedia at good quality in a cluster-based delivery scheme is highly dependent on cluster head lifetime. In this context, simulation-based testing has been done in order to analyze the performance of the proposed algorithm in comparison with that of the most commonly used clustering algorithm in VANETs, Lowest-ID [5]. We evaluated mean lifetime of cluster head, mean throughput of the multimedia packets and the loss of multimedia packets, for both algorithms. Realistic simulation scenarios that implied the variation of vehicle speed (30km – 70km) and number of lanes were built. UDP flows with a constant bit rate (CBR =

0.45Mbps) traffic were used to simulate multimedia streaming. Other key parameters of the simulations performed are described in TABLE I.

TABLE I. THE VALUES OF SIMULATION PARAMETERS

Parameters	Values
Network topology	Manhattan Grid
Number of hops	{1, 2}
Transmission range (d_{max})	200m
Vehicle's maximum speed (v_{max})	[30km/h – 70km/h]
Drivers imperfection(sigma)	0.5
Number of lanes	{2, 4}
MAC protocol	802.11p
Vehicles information message	500 bits
Multimedia packets	1200 bits
Routing protocol	AODV
Simulation time	300s

Two main sets of simulations were performed in order to analyze the performance of the proposed Utility Function-based clustering algorithm in 1-hop and 2-hop variants against the Lowest ID algorithm.

In the first set of simulations, the values of mean CH Lifetime, mean throughput and loss were analyzed as functions of vehicle speed. The maximum speed was varied in the interval [30km/h – 70 km/h] and the number of lanes was set to 2. The results are illustrated in Figure 3. Figure 4. and Figure 5. and demonstrate a direct proportionality between Mean CH Lifetime and throughput. As stated before, the quality of multimedia transmission is highly dependent on CH lifetime. This can be seen through visualization, but the authors are planning as future work to investigate more and see if a mathematical correlation is possible to be defined.

Both Utility Function-based algorithms (i.e. 1-hop and 2-hop) provide longer CH lifetime and in consequence, better throughput. In terms of loss, the 1-hop Utility Function-based algorithm provides better results than the Lowest ID. On the other hand, the 2-hop Utility Function-based solution has a slightly larger loss than the Lowest ID and grows with the increase in the speed. However, in terms of tradeoff between throughput and loss, the 2-hop Utility Function based algorithm still provides better performance than the Lowest ID algorithm. The degradations in terms of loss are explainable due to the multi-hop transmissions.

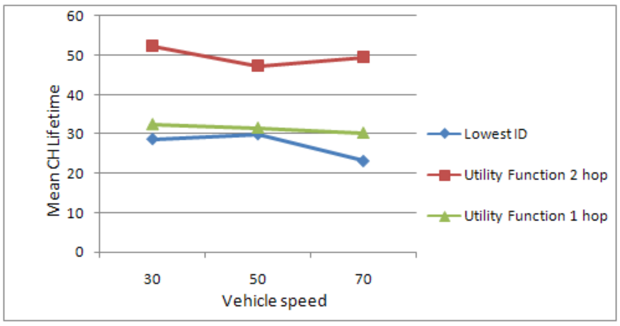

Figure 3. Mean Cluster Head Lifetime vs. Vehicle Speed

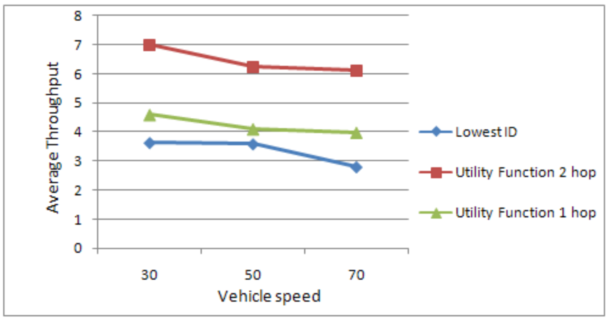

Figure 4. Average Throughput vs. Vehicle Speed

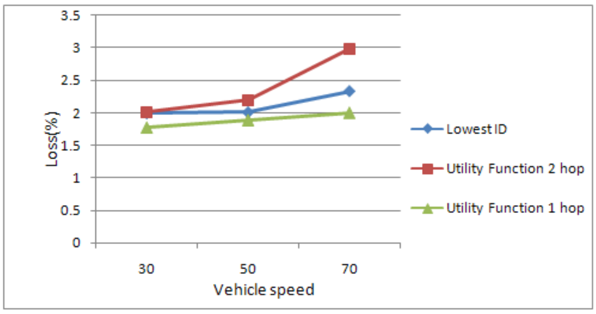

Figure 5. Loss vs. Vehicle Speed

In the second set of simulations, the vehicle speed was set to 50km/h and the number of lanes was varied between 2 and 4. The results are illustrated in Figure 6. Figure 7. and Figure 8. and based on them, similar conclusions can be drawn as in the first set of results. The 1-hop Utility Function-based algorithm provides better performance in terms of both throughput and loss, while for the case of the 2-hop Utility Function-based algorithm, the loss is slightly higher and the performance degradation increases with the number of lanes. However, in terms of tradeoff between throughput and loss, the 2-hop Utility Function based algorithm still provides better performance than the Lowest ID algorithm.

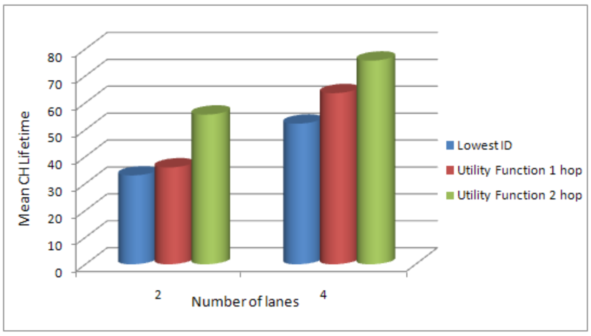

Figure 6. Mean Cluster Head Lifetime vs. Number of Lanes

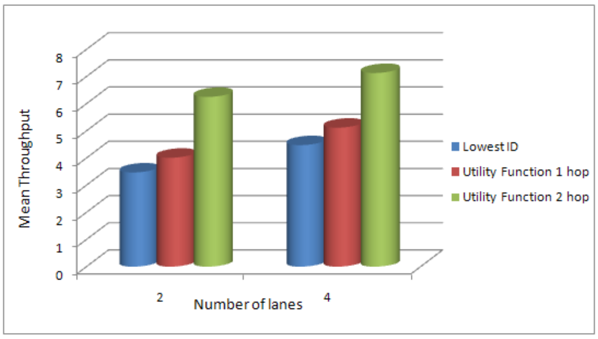

Figure 7. Mean Throughput vs. Number of Lanes

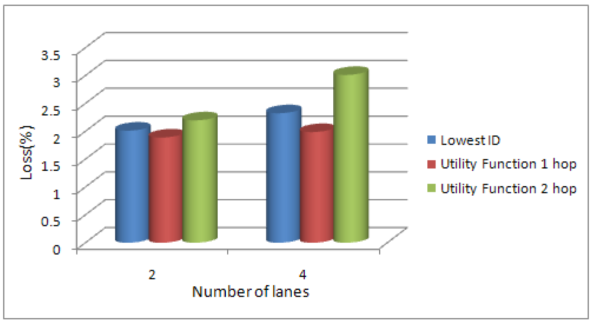

Figure 8. Loss vs. Number of Lanes

VI. CONCLUSIONS AND FUTURE WORK

In this paper a novel user-oriented cluster-based multimedia delivery solution over VANETs was proposed. The solution delivers multimedia content based on the preferences of the vehicle passengers. The proposed approach reduces both the cost of the infrastructure used in the deployment and the energy consumed at the RSU unit level. The well established QOAS was employed for multimedia transmissions in order to enable high-quality multimedia delivery. The simulation-based testing showed that the proposed algorithm for cluster head selection assures a better mean lifetime of cluster head than that recorded in case of using the classic Lowest-ID algorithm. This positively influences the quality of multimedia transmissions in terms of throughput and loss.

As future work, the authors are planning to do tests that imply real video streaming over VANETs and to continue the analysis of clustering performance metrics versus multimedia quality transmissions with the declared purpose of improving the clustering solutions for multimedia delivery.

VII. ACKNOWLEDGEMENT

The support from the Dublin City University Daniel O'Hare Scholarship and LERO (Grant no. 10/CE/I1855) is gratefully acknowledged.

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