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Improving VANET Protocols using Graph Structure Approach

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***Abstract*— It is very difficult to develop an efficient protocol for message broadcast in vehicular ad-hoc network that supports communication between vehicles and road side units with minimum delay, minimum overhead and maximum reachability. In this paper we show that if we study graph theoretic characteristics of VANETs because they don't follow scale free and small world network properties, we can improve message broadcast in VANETs. We study urban and highway VANETs graph scenario for different capacities and different network densities. We study properties of graph like average shortest path length, node degree distribution, clustering coefficient and connectivity. For different parameters we develop separate analytical model for both urban and highways VANETs and study VANETs from graph structure point of view. After that we observe that clustering coefficient do not depend upon network density and network size. We study the impact of network density on connectivity and also study VANETs node degree distribution. We then show how this information can be used to reduce overhead in urban vehicular broadcasting protocol (UVCAST) with no major reduction in performance of existing protocol.

***Keywords*— Connectivity, Node Degree, Vehicular Adhoc Networks, Routing Protocols

I. Introduction

Vehicular ad-hoc network is very interesting research area and is getting more popular day by day. In vehicular ad-hoc network vehicles or moving cars make an ad-hoc network. In VANETs these vehicles either communicate directly or with the help of some infrastructure like road side units (RSUs). Road side units may work as either router or access point with the help of which more number of vehicles stay connected. Road side units are overall controller of on road activities. Vehicles or nodes in VANETs communicate with the help of dedicated short range communication (DSRC) protocol. DSRC is basically IEEE 802.11p [1] amendment of IEEE 802.11a for low overhead operations in VANETs. DSRC IEEE802.11p is generally referred as wireless access in vehicular environment (WAVE). Developing routing protocols for this type of network is very challenging task due to unique properties of VANETs. Communication protocol for such type of network should be able to maximize use of limited bandwidth. Such a protocol should be able to transmit message to all vehicles with minimum overhead and minimum delay. This is very difficult task due to unique properties of VANETs like random and high speed of vehicles, variable vehicle density and dynamic topology of nodes. To construct efficient routing protocol for VANETs we need to first study characteristics of VANETs. A number of studies and research is already done to study unique properties of VANETs mainly addressing mobility of nodes, dynamic topology and bandwidth constraints. In this paper we study VANETs from graph structure perspective to gain in depth knowledge of network structure .

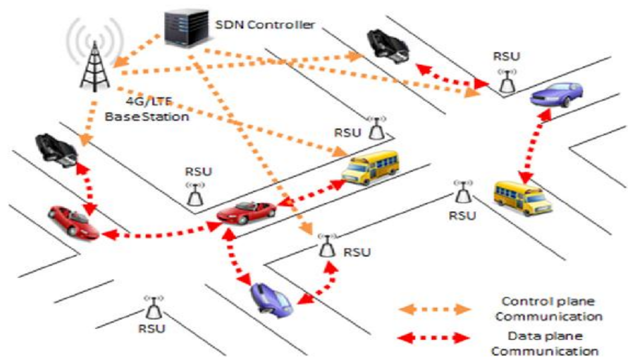

Figure 1- Architecture of VANETs

After that we will use this knowledge to improve existing VANETs routing protocols. Complex networks are of two types with specific graph characteristics: small world and scale free networks. A number of ad-hoc networks like computer networks, human social network and even biological networks come under category of complex networks [6]. Graph structure is how nodes are connected in a network. Graph properties define speed of movement between nodes. It is very important to study graph characteristics of VANETs to examine structure of network before designing a complex protocol.

In this paper we study graph structure of VANETs by using four parameters: 1) node degree distribution 2) connectivity 3) clustering coefficient and 4) average shortest path length. First and second parameters will help to get observations on connectivity at local and global scale. Third and fourth parameters will help to get observation whether or not node's neighbours are also neighbours of each other. We study these parameters in both highway and urban scenario by constructing analytical models and also real life data. Observations derived from study of these parameters helped us to design techniques to improve performance of urban vehicular broadcast protocol (UVCAST). These techniques minimize communication overhead in UVCAST protocol while maintaining the performance of protocol. In this paper we construct analytical models that estimate these network parameters on highway and urban scenario with separate vehicle densities and different sizes. We also show how UVCAST with additional mechanism reduces overhead in communication in VANETs.

The paper is organised as follows: Section II contains related work and section III describe real life data used for simulation. In Section IV we analyse various network parameters from graph structure perspective through analytical models. Section V describes uses of data and models analysed in Section III and apply them to improve performance of UVCAST protocol. Section VI elaborates simulation and results. Section VII describes concluding remarks about work done in this paper and also describes future work possibilities.

II. Related Work

VANETs is type of mobile ad-hoc networks [18].There exist various number of VANETs [17] broadcast protocols in literature but we will discuss only those methods that are relevant to our work. In [2] Direction-aware Function-Driven Feedback augmented Store and Forward Diffusion (DFD-FSFD) protocol is discussed. In this scheme each message has propagation function which defines region of interest [ROI] Messages are stored and carry forward in disconnected areas. In [4], AckPBSM (Acknowledged Parameter-less Broadcast in Static to highly Mobile protocol) is presented. This scheme uses concept of Connecting Dominating Set (CDS) for transmitting message in high density regimes. In case of disconnected regimes packets are sent after receiving acknowledgments attached with periodic hello messages. In [6] and [7] a probabilistic broadcasting method for highway VANETs named Irresponsible Forwarding (IF) is presented. It tries to send messages very fast and also reduces collisions. Then [8] presents CAREFOR, an improvement to IF based on two things: (1) allowing separate communication ranges for source node and receiver to be taken for estimating whether rebroadcasting is required or not (2) Determine that collision will occur or not at each node and rebroadcasting only to node where collision may occur depending upon the number of vehicles in that region. In [5] an urban VANET broadcasting protocol (UV-CAST) is presented. In our work, we have referred UV-CAST method for message broadcast in urban area because this protocol is lightweight and does not require infrastructure support which eliminates the disadvantages of existing methods discussed above. The details of UV-CAST protocol are given in section V. In our work we will try to improve existing UVCAST protocol by studying characteristics of urban VANETs from graph structure perspective and by adding some techniques to reduce communication overhead that are not present in the original UV-CAST protocol. Watts and Strotgatz in [9] study network approaches from graph structure perspective for a small world network. Despite the above mentioned studies, no study found in literature that presents extensive analysis of properties of highway and urban VANETs from graph structure perspective. The properties that we will are clustering coefficient, average shortest path length, connectivity and node degree distribution. Work like in [10] recognises the benefit of analysing VANETs from graph theoretical perspective and studying and using concept of scale free and small world networks. In this work authors claim that VANETs posses properties of small world and scale free network. In this paper authors try to construct a scale free highway VANET and observe some properties which may match with scale free network in some cases. So a good technique is to learn characteristics of actual of existing VANETs in literature to improve message broadcast in VANETs.

In our work we will try to learn characteristics of VANETs from graph theoretical way to better understand the network structure, behaviour of network and their similarities to other self organised scale free networks that are given in literature.

III. REAL LIFE DATA

We have collected real life data for highway and urban networks to analyse graph structure of these scenarios. The data collected contains different position of nodes and different vehicle density at different time of a day that seems like real traffic pattern. We have used data generated by cellular automata model [11] in case of urban VANETs. The cellular automata model considers blocks of size 125*125. We assume that two nodes can communicate with each other in line of sight if they are at 1-hop away from each other with in 250 meter distance or can communicate up to 140 m distance in non line of sight. We consider sample determined by Berkeley Highway Laboratory [12] for highway VANETs. This gives data about the time and velocity of the nodes passing through a particular region of the highway, that we elaborate considering that the nodes movements are constant. For highway VANETs we assume that two nodes can communicate with in distance of 250 m in line-of-sight at all times. By considering this information, we study snapshots of both highway and urban VANETs and analyse graph structure of nodes where nodes are moving cars and there is edge between those nodes that can communicate with each other that are 1-hop away from each other. Next we consider three connectivity regimes and for each scene, we take three connectivity areas low, medium and high connectivity and their equivalent vehicle densities. Now this means varying number of nodes in cellular automata model for urban and on the other hand in case of highway VANETs it means collecting connectivity information from separate times of the day. The information is given in Table 1.

Table1: Connectivity v/s density in highway and urban areas [11].

4 km^2 urban area		25 km long highway		
Density (veh/km^2)	Connectivity (%)	Density (veh/km)	Connectivity (%)	Time of day
12	4	5	4	01:00–03:00
65	49	24.0	67	10:00-12:00
85	92	83	98	15:00-17:00

IV. NETWORK CHARACTERSTICS

Here we will discuss different characteristics of VANETs depending upon the graph theoretical analysis and analyse them with existing theoretical models on clustering coefficient, connectivity, average shortest path length and node degree distribution. These concepts are defined below:

1. Node degree: node degree can be defined as total number of edges connected to it. These edges are known as communication path between nodes.

2. Connectivity: it is can be stated as number of pair of vehicles which are able to communicate between themselves in a network. If we think of single node connectivity can be defined as number of pair of nodes out of total nodes with which this node can communicate.

3. Clustering coefficient: from network point of view it is defined as probability that if two nodes are connected to a node then these nodes are also connected with each other. In other words it is equal to number of pair of nodes connected to a particular node are also connected with each other.

4. Average shortest path length: it can be considered as average number of hopes between all possible pairs of nodes in a network. It can be represented mathematically by assuming average shortest path length P that increases proportionally to logarithm of total number of nodes K in a network [9].

$$P=\log(K) \quad (1)$$

A number of small world and scale free networks can be studied from [13]. In these networks number of nodes having high degree is much greater than number of nodes with low degree. The equation for average shortest path length is given below.

$$P_m(m)= m^{-z} \quad (2)$$

Where m is node degree and z is some constant depending upon particular distribution.

A) Node degree distribution

It can be defined as probability distribution of the number of nodes which are 1-hop away from each node.Figure2 represents node degree distribution for varying densities in area of 4km^2 for urban VANETs and their Gaussian fits.

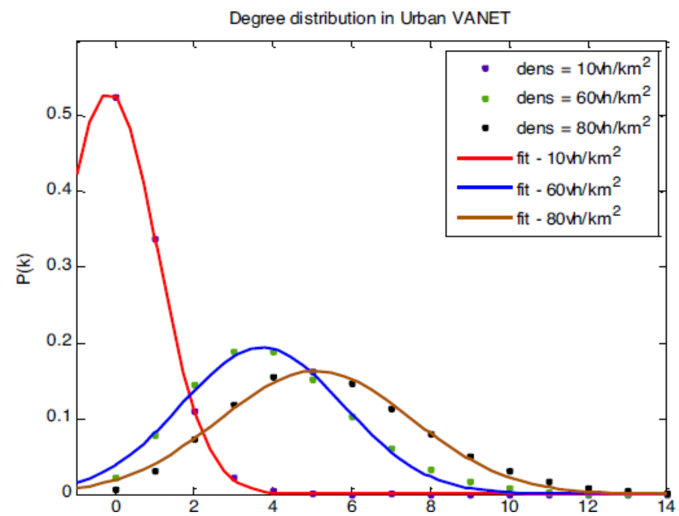

Figure2: Node degree distributions with varying densities and their corresponding Gaussian curves of urban VANETs [3].

These curves are drawn according to value of table2 by using following formula

$$N(K)=x.e^{-((k-y)/z)2} \quad (3)$$

Where x, y and z are constants. The above equation is valid only all values greater than zero.

Table2: Inputs for node degree distribution in urban VANETs for best Gaussian fits [3]

Density (veh/km^2)	X	Y	Z	r-square	sse
12	0.5415	-0.184	1.704	0.9998	0.00002275
65	0.2032	3.828	2.994	0.9942	0.000756
85	0.1367	5.198	3.567	0.9943	0.0005929

So we can see from Figure2 and values from Table 2 that by using data provided by cellular automata model the Gaussian curves fit very well for urban VANETs.

B) Average shortest path length

Average shortest path length is also very important parameter. The value of this parameter is also determined by using real life data. Average shortest path length is drawn as a function of network area by using data from cellular automata model. These fits are parameterized by value given in table3 by using following formula

$$P(Area) = x.Area^{y} + z \quad (4)$$

Table3: Inputs for Average Shortest Path Lengths of the best power fits in urban VANETs

Density (veh/km^2)	x	y	Z	r-square	SSE
12	-0.410	-0.31	1.55	0.9753	0.0001096
60	3.381	0.660	1.52	0.9963	0.9074
80	6.505	0.462	-1.0	0.9991	0.208

From figure3, we see that for all the three types of densities the power fitness curve fits well. Again we see that that value of variable y is close to 0.5 in Table3 for the networks with medium and large densities. It clears that average shortest path length is most likely to increase when there is high connectivity.

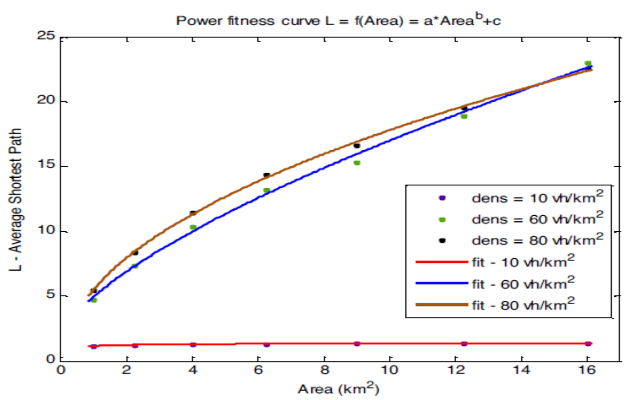

Figure3: Average shortest path lengths in urban area as functions of the network area and vehicle density [3].

C) Clustering coefficient

To measure clustering coefficient for urban VANETs, lets us assume that a node is connected with other nodes which are at distance of less than r meters. Now we can say clustering coefficient is probability that if two nodes are connected to a common vehicle then these nodes are also connected with each other. Clustering coefficient is also probability that if two nodes are r meter away from a common node then these two nodes are also less than r meter away from each other. Figure 4 shows variation of clustering coefficient with respect to different network densities in urban scenario.

D) Connectivity

Figure 5 shows connectivity versus vehicle density for urban scenario by using data from cellular automata model. From figure we observe that connectivity values mainly vary when vehicle density is between 40 and 80 vehicle per km square.

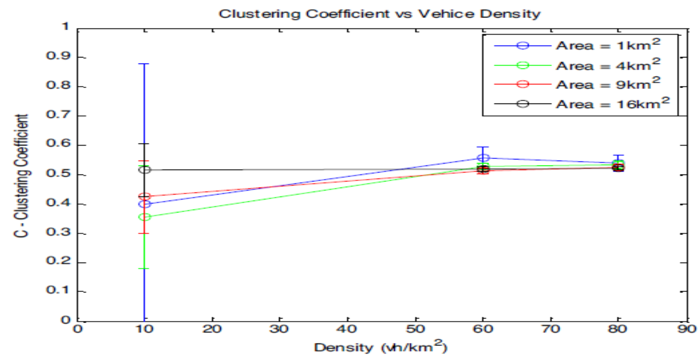

Figure4: clustering coefficient v/s network density in urban scenario [3].

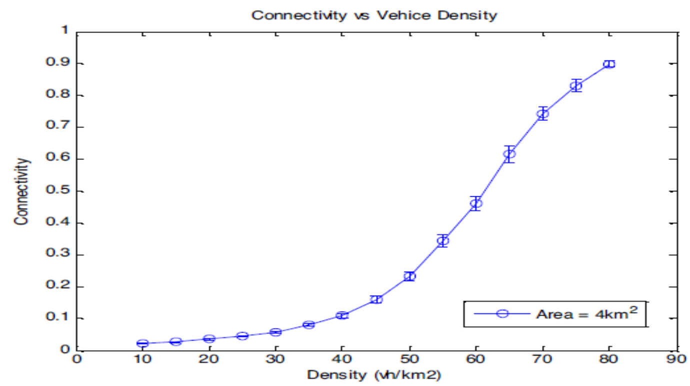

Figure 5: connectivity v/s vehicle density for urban scenario [3].

V. IMPROVEMENT OF UVCAST PROTOCOL

In [5] UVCAST protocol is proposed to transmit messages in urban area with the goal of broadcasting safety message to nodes in a given region of interest (ROI). It solves problem of both high vehicle density and low vehicle density region (i.e. broadcast storm and sparse networks). Figure6 shows that vehicle may either operate in high vehicle density regime or low vehicle density regime. In high vehicle density area proposed scheme to reduce delivery of redundant messages or to reduce broadcast storm depending upon position of vehicle and distance from previous relay. Before rebroadcasting a message node determines average waiting time and transmits message with probability X. Store and carry forward task is assigned to cars which are not in high density area. Detail working of protocol can be studied from [5]. Figure6 also shows additional X and Y that are used to improve performance of UVCAST protocol. UVCAST protocol gives very good results and ensures delivery of message to nodes in certain region of interest (ROI) with minimum overhead and minimum delay but still there is room for improvement in reachability, average received distance and overhead in terms of number of messages broadcasted and number of message delivered. Note that results shown in figure2 for node degree distribution indicate that a vehicle may have maximum 2 neighbours in case of low density area and each node has more than 3 neighbours in high density area.

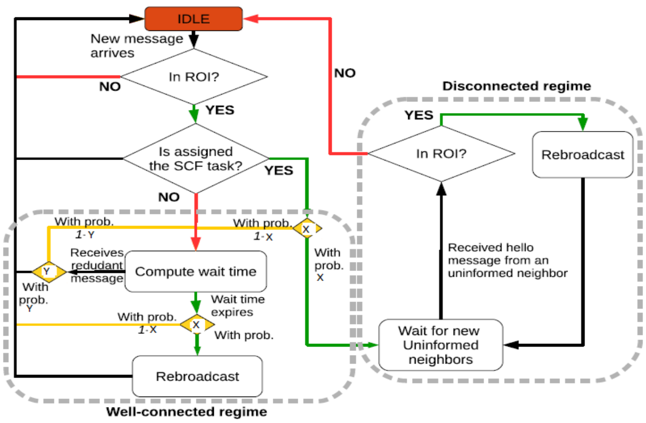

Figure 6: flowchart for the UV-CAST protocol with additional X and Y mechanisms [5].

Based upon this indication assume that a vehicle is in low density area if $k_{med}<2$ and vehicle is in high density area if $k_{med}>3$. In proposed scheme we introduce two mechanisms X and Y. Mechanism X is used to suppress the broadcast storm in high vehicle density and Y is used to improve network reachability in low density area. Now we propose that to decrease duplicate message in well connected regime reduce the number of store and carry forward nodes in well connected regime. In simple words when wait time expires a node will rebroadcast with probability X according to below given equation.

$$X= \{0.5+0.5/k_{med}^{-3+1},\ k_{med>3} \quad 1,\ Otherwise\} \qquad (4)$$

On the other hand to increase network rechability in disconnected regime nodes are allowed to rebroadcast again and again before timer expires. This may increase some overhead but as this scheme will work only in low density regime; this will not create a major problem. So a vehicle in disconnected regime should continue to rebroadcast despite of receiving redundant messages with probability 1-Y where Y can be defined by the following equation.

$$Y= \{\ 0.5 + 0.5*k_{med}/2,\ k_{med<2} \quad 1,\ Otherwise\} \qquad (5)$$

VI. SIMULATION AND RESULTS

We have tested the above proposed scheme in a simulation environment same as described in manhattan grid scenario [5] by considering 1km*1km area as region of interest (ROI) around an accident scene. In starting 10 minute warm up time is given. After that source node broadcasts a message from middle of network and data is collected after 2 minutes of broadcast of message.

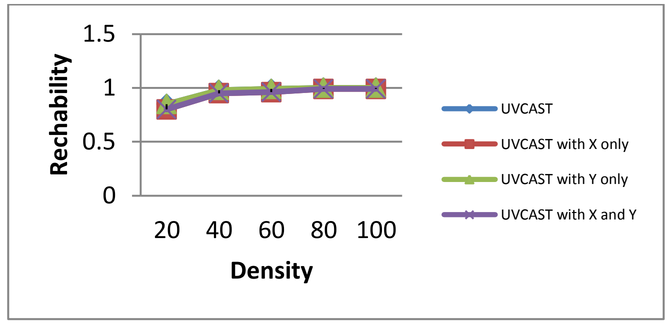

Figure 7.1: Density vs Rechability

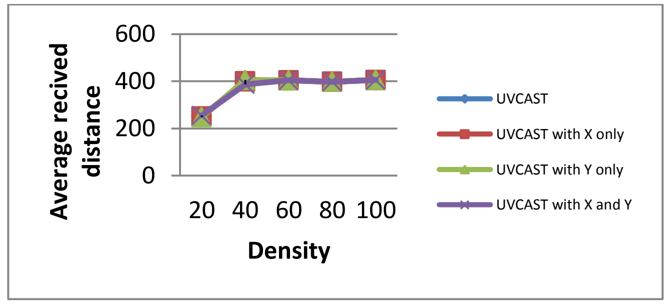

Figure 7.2: Density vs Average recieved distance

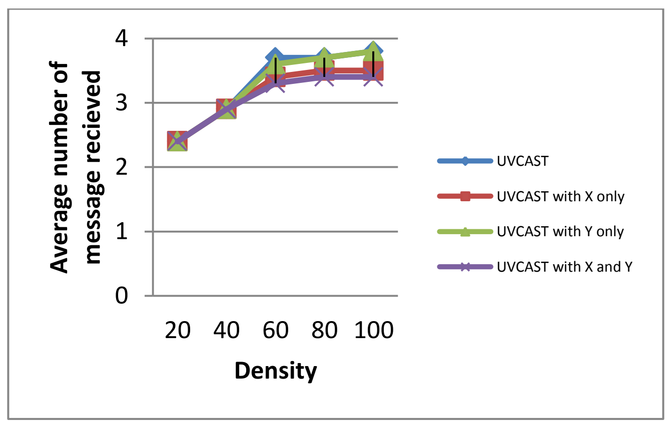

Figure 7.3: Density vs Average number of message recieved

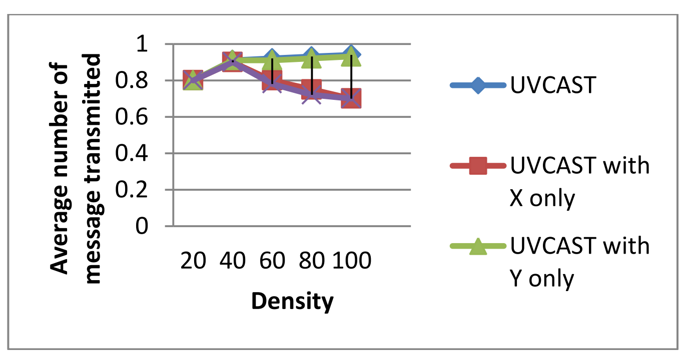

Figure 7.4: Density vs Average number of message transmitted

Total 15 simulations were run. K_{med} is calculated based on exponential moving average number of neighbours of a node. Simulation results of both X and Y by using four parameters reachability, average received distance and average number of message received per vehicle average number of message transmitted per vehicle are shown in figure7. In figure7 performance of proposed scheme is compared with UVCAST protocol. The bottom two plots show that X mechanism significantly reduces the broadcast storm in high density networks. The effect of Y mechanism is negligible in well connected regime. For a network with vehicle density 100 vehicles per km^2 about 20% improvements in terms of number of average message transmitted per node is estimated when both X and Y techniques are in use. We have also observed that Y mechanism helps X mechanism to reduce number of message transmitted in received per vehicle in high density networks. While proposed schemes are not effective disconnected networks but results in medium and high density networks for improvement of overhead seem quite promising.

VII CONCLUSION AND FUTURE SCOPE

In this paper we have studied highway and urban VANETs from graph structure perspective by taking into consideration a number of network properties like node degree distribution, connectivity, clustering coefficient and average shortest path length. We have designed and evaluated analytical model for these parameters for different network sizes and densities. After that we proposed mechanism to enhance urban vehicular broadcasting protocol. We tested this mechanism by running simulations which gave us good reduction in network overhead without affecting the performance of UVCAST protocol. As for future work we will try to include mobility pattern in proposed scheme.

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