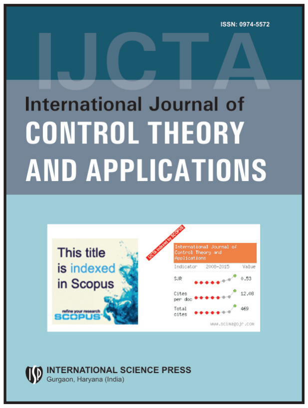

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Tracking and Congestion Estimation in Smart and Connected Vehicles based on VANET-WSN Architecture

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Abstract: The challenges of the modern traffic management system include road safety, congestion control and reduced pollution by effective fuel consumption. To attain these goals, many improvements are performed in the traditional traffic management system as well as in the vehicles. With the advancements in the field of Information and Communication Technology (ICT), more and more approaches rely on connected vehicles, where vehicles are equipped with computing and communication capabilities, making the vehicles smart. These smart and connected vehicles facilitate automatic monitoring and coordination among themselves allowing us to provide intelligent ways of transportation. We have used VANETs (Vehicular Ad-hoc Networks), one of the emerging applications of ICT in vehicular networks to track, monitor and coordinate the on-road vehicles. In VANETs, the vehicular nodes are capable of gathering information related to safety, comfort, efficiency, etc. and communicate with each other as well as with the roadside infrastructures for exchanging messages to increase the passenger safety on the road, making them the smart vehicles. Here, we have used an architecture based on VANETs and WSN (Wireless Sensor Networks) for identifying and monitoring the on-road mobile vehicular nodes. We have proposed the use of a new method to calculate the on-road vehicular density based on the number of neighbouring vehicles and the complexity of the roadmap. This information can be used by the vehicles effectively for congestion control by analysing the current on-road traffic and also to approximate the future traffic density. We have simulated the model using Cooja simulator and obtained the experimental results to validate our approach. Finally, we have analysed the obtained results to demonstrate the efficiency of the proposed system.

Keywords: VANETs, WSN, ITS, Congestion, Density estimation, Cooja.

1. INTRODUCTION

The popularity of private vehicles on the urban road scenario has increased significantly over the past few years. As a result, the urban traffic is getting more and more crowded. Hence, traffic monitoring is becoming one of the important issues in recent smart-city infrastructure around the globe. These concerns include traffic congestion and disastrous road accidents that usually cause a significant loss of time and money and also cause hazardous environmental pollution. Any type of congestion on the roads basically leads to major losses in terms of health and wealth. This calls for an urgent need to improve the condition of current traffic management system. The advancements in Information and communication technology (ICT) provide a new trend for intelligent traffic development. This research proposes to combine the Vehicular Ad-hoc Networks (VANETs) with the communication capabilities of Wireless Sensor Networks (WSN) to develop a robust framework for intelligent traffic information management system by tracking, monitoring and coordinating the mobile vehicular nodes on the road.

VANETs are special types of wireless communication networks which support cooperative transportation among the vehicles on the road. VANETs mainly consist two types of nodes, the on-road vehicles that are mobile in nature and the fixed roadside infrastructures. The on-road vehicular nodes, also called the On Board Units (OBUs) are equipped with wireless communication modules and are capable of data collection and exchanging information related to safety and comfort with other vehicles as well as with the roadside infrastructures. The roadside infrastructures, also called as Road Side Units (RSUs), act as base stations and can collect data from the OBUs, from other RSUs and sometimes from a central server controlling the entire system. VANETs mainly support two types of communications: vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). The highly mobile vehicular nodes in VANETs act as centres for communication and relays, forming a hybrid and dynamic network together with other nearby vehicles and RSUs. Due to the high mobility of nodes, the connection may be broken frequently. Thus, VANETs are characterised by high mobility, dynamic topology, frequent disconnections, variable network density, etc. The specific characteristics of VANETs trigger the development of attractive and challenging services and applications, including road safety, road status monitoring, driver's assistance, traffic flow management, environmental protection, and mobile infotainment [1]. Thus, VANETs form the most important component of Intelligent Transportation System (ITS).

There are numerous wireless access technologies available today, which can be used to provide the radio interface required by the vehicles in order to communicate with each other in V2V communication, or with the RSUs in V2I communication. These communication technologies intended to improve road safety, traffic efficiency and to provide driver's assistance and passenger's comfort by enabling a set of safety and non-safety ITS applications [2]. Wireless Sensor Networks (WSN) is a promising technology which is becoming more mature and is gaining momentum as one of the enabling technologies for the future Internet of Things. Therefore, it is being applied ubiquitously and in particular to ITS for automatic data collection and processing. WSN consist of medium to large networks of inexpensive wireless sensor nodes capable of sensing, processing and distributing real-time information acquired from the environment through the collaborative effort of nodes [3]. WSN provide significant advantages both in cost as well as in distributed intelligence. On one hand, installation and maintenance expenses are reduced because of the use of low-priced devices which do not require any physical communication media. Moreover, WSN cannot be regarded just as stand-alone systems intended for ITS; on the contrary, they should be considered in the ITS context as additional components of a heterogeneous system, where they cooperate with other technologies such as VANETs [4].

Congestion control on the roads being one of the important safety applications of ITS, attracts the attentions of many researchers. Vehicles can communicate among themselves or with the RSUs to reveal their location information on the road. This real-time data collected from the vehicles are used to compute the local density of the nodes in a particular road segment which can be extended further to estimate the global density. These estimations can be made by one of the local RSUs, in centralized density estimation or by one of the vehicular node in Distributed density estimation scheme. The results are broadcasted to all the vehicles within the transmission range which can be analysed to predict an approximation on the future density.

The aim of this paper is to present a framework for real-time traffic information acquisition and monitoring based on VANET architecture and utilizing the wireless communication technique of WSN. The primary characteristic of the adapted traffic information infrastructure is its capability of integrating different technologies with the existing communication infrastructures. The framework allows gathering real-time traffic data from the mobile vehicular nodes and monitoring the traffic flow by estimating the current local density in a given road segment using a roadside infrastructure.

The remainder of the paper is organized as follows. Section 2 presents some of the related works that exist in the literature. Section 3 discusses about the proposed model which includes the architecture and functionalities of the system. It also gives the formulation of the proposed metric to calculate the vehicular density. Section 4 shows the simulation environment used to evaluate the performance of our system where we present and analyse some experimental results to validate the proposed model. In Section 5, we conclude our study and discuss the scope for future works.

2. RELATED WORKS

VANETs is gaining more and more popularity as many researchers taking their interests in the challenging field of ITS. There exist a number of works in the literature that focus on using VANETs to design robust solutions for various ITS applications. In most of the earlier studies, infrastructure-free frameworks were used for realising the ITS applications based on VANETs.

In [5], Alonso and Mecklenbraeuker proposed a decentralized congestion control scheme that is suitably adapts to variable traffic densities. Sanguesa et. al., [6] studied the effect of adverse vehicle density conditions on the performance of different warning message dissemination schemes. Bilal et. al., [7] presented a distributed mechanism for the estimation of the vehicular density considering multiple road factors, such as road length and junctions. In [8], Sanguesa et. al., proposed a mechanism to estimate the vehicular density in urban scenario which uses the number of beacons received per vehicle and the topological characteristics of the environment where the vehicles are located as input parameters. Akhtar et. al., [9], proposed fully distributed and infrastructure-free mechanisms for estimating the vehicular density. The authors adapted and implemented three fully distributed algorithms based on system size estimation. In the above works as well as in [10], [11], [12], the authors have used a decentralized architecture for VANETs to realise various applications, where the vehicles communicate among themselves (V2V communication) without involving any RSUs. The infrastructure-free architectures were preferred over the infrastructure-based architectures due to the fact that the earlier is cost effective while the later may suffer from bottle neck where the RSUs are burdened with the task of processing the real-time data gathered from all the on-road vehicles. But, the reliability of the system reduces in infrastructure-free architecture due to the inherent characteristics of VANETs such as high mobility of the nodes, dynamic topology and frequent disconnections. Though the centralized architectures may suffer from single point failure, but it is simpler, more reliable and easy to implement.

The density of nodes plays an important role in congestion estimation and control in VANETs which form the basis of communications in a cooperative environment like ITS. We have found several works in the literature that rely on estimating the current vehicular density to improve the congestion on the road. Many earlier works use infrastructure-based approaches to calculate the vehicle density. Traditionally road traffic density has been estimated using a number of techniques such as roadside magnetic loop detectors, surveillance cameras, wireless vehicle sensors, pressure pads, roadside radar and infrared counters [13], [14], [15]-[19]. However, these techniques require the detection devices to be installed in advance, at various locations on the road map. Consequently, the infrastructure-based vehicular density estimation techniques are limited to regions where detection equipments are deployed. Also these solutions are costly and less reliable as the inputs taken by these devices can be affected by the environmental conditions such as rain, wind clouds, etc.

3. PROPOSED MODEL

The major tasks of the proposed system are, to detect the on-road mobile vehicular nodes and obtaining the detailed information about a vehicle including its position, identifying the vehicle from the collected data, using the real-time data to compute the current density of the vehicles in a given road segment by the RSUs which can be extended further to estimate the global density and finally the RSUs send these estimations to the vehicles within their transmission range. These estimated density information help the vehicles to realise the congestion on the road and hence, to choose the suitable route for safe and comfortable driving.

A. System Architecture

The proposed model is based on infrastructure-based VANET's architecture. It follows a hybrid architecture as shown in Figure 1, where VANET is combined with WSN to facilitate communication between the nodes. The OBUs are randomly distributed in multiple lanes along the roads and the RSUs are placed at equidistance. These vehicular nodes are realized with sensor nodes (motes) and the transmission ranges are set to be in the order of several hundred meters.

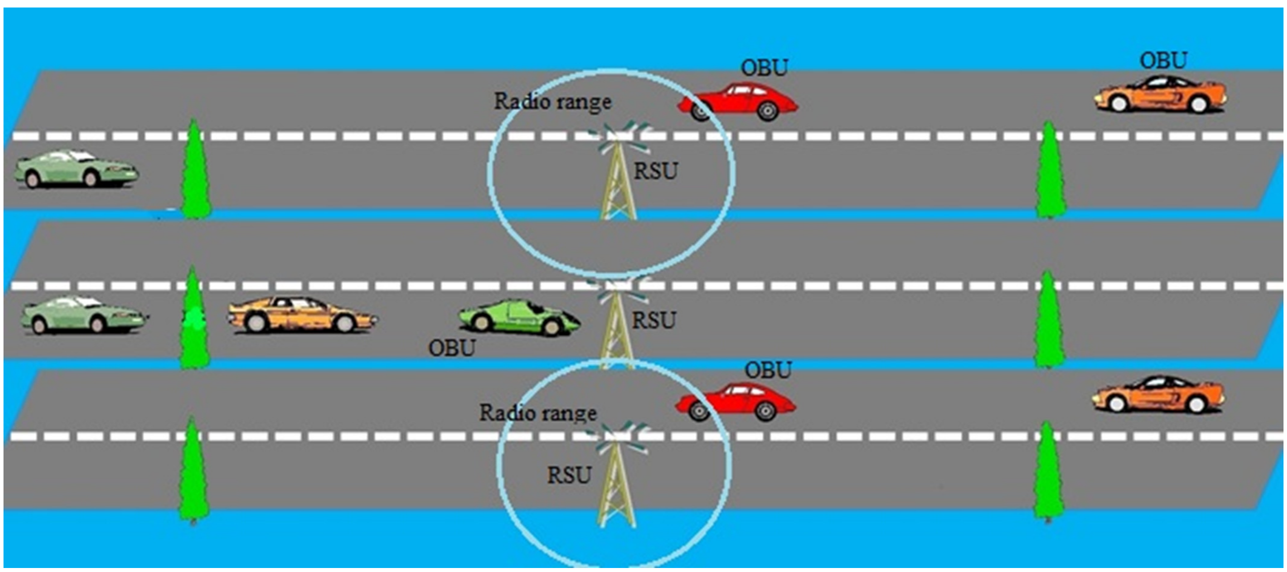

Figure 1: VANET-WSN hybrid architecture

B. Vehicle Tracking

A vehicle after entering the transmission range of a RSU passes a beacon message to RSU at every time interval T_{RSU}. The beacon structure is shown in Figure 2 and the list of parameters of the message are described in Table I.

VID	TS	VOID	VD	U

Figure 2: Beacon Structure

At a regular interval, these information are sent to the RSUs. Each RSU maintains a list of vehicles transmitting these messages called the *neighbour_list*. After a fixed interval of time when a RSU does not receive the message from the particular vehicle, it removes the vehicle from the list. This list of neighbouring nodes at each RSU is used to calculate the vehicular density on the road.

Table 1
Message parameters and acronyms

Header	*Acronym*	*Meaning*
Vehicle ID	VID	ID of the vehicle.
Timestamp	TS	GPS timestamp of the vehicle.
Owner's ID	VOID	ID of Vehicle owner.
Vehicle Datasets	VD	Vehicle's manufacturing details.
Speed	U	Speed of vehicle.

In order to reduce the congestion in the communication channel, T_{RSU} is taken in order of one or few seconds (as frame transmission time is in order of milliseconds).

C. Density Calculation

The density of the vehicles is an important parameter for analysing the congestion level in a road. The on-road vehicular density depends on many parameters such as, number of vehicles on the road, the total area covered by the road, structure of the road, etc. We have formulated some expressions for calculating the local as well as the global vehicular densities for a given road.

Consider a section S_i of the road segment S, covered by a particular RSU R_i, the total area covered by S_i is A_i in km^2 and N_i is the number of vehicles in the *neighbour_list* of R_i. Then the estimated local density D_i of the vehicles on the road segment S_i can be computed by the following equation:

$$D_i\left(N_i, S_i\right) = \frac{N_i}{A_i \times L_i} \tag{1}$$

where, L_i represents the number of lanes in S_i.

The estimated global density D on the road segment S can be computed as,

$$D(N, S) = \frac{\sum_{i=1}^{r} N_i}{A \cdot \frac{1}{r} \sum_{i=1}^{r} L_i} \tag{2}$$

where, r = Total number of RSUs placed throughout the road S and A = Area covered by S.

4. IMPLEMENTATION AND RESULTS

The proposed model is implemented using COOJA, the network simulator for Contiki OS. We have considered 10 different sink nodes as the RSUs which are placed at 200 meter apart. We have tested the scenario by performing rigorous simulation taking different number of vehicular nodes which are realized by the Sky motes. Cooja's mobility model is used where the speeds of the vehicles are changed randomly in the range of 20 km/hr to 80 km/hr. The RSUs are placed at 200 meter apart. The vehicular nodes are randomly distributed in an area within 2000m $\times$ 200m which we choose to realize a segment of the road map. A simulation scenario is shown in Figure 3.

We have used RPL (Routing Protocol for Low Power and Lossy Networks), a commonly used IPV6 protocol for WSN, as the routing protocol for data communication between the vehicular nodes and the RSUs. We chose different transmission ranges varying from 100 metres to 300 metres to analyse the performance of the system.

Table 2
Simulation Parameter

Parameters	*Values*
Operating system	ContikiOS 2.7
Simulator	Cooja
Mote type	Tmote Sky
Simulation area (m^2)	2000×200
Number of nodes	50-100
Number of sink Nodes	10

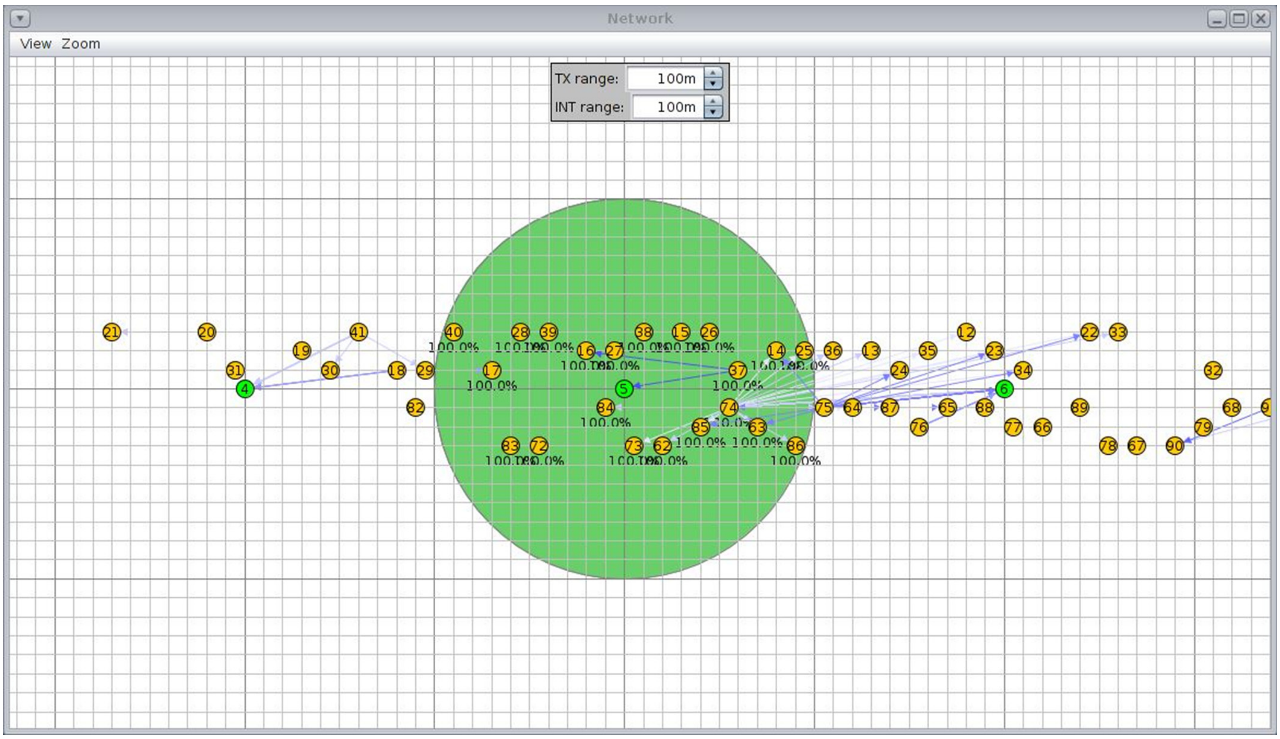

Figure 3: A Simulation Scenario in COOJA

A. Simulation Results

1. *Discovery of Vehicles by the RSUs*: As soon as a vehicle enters the transmission range of a RSU, it sends a message to the RSU at a regular interval of 2ms. The RSU upon receiving the message, put the vehicle in its *neighbour_list*. The destination oriented routing in RPL handles the dynamic topology and frequent disconnection properties of VANET effectively. Figure 4 shows the discovery of all vehicles by a RSU those come in its transmission range.

   We considered 50 vehicular nodes and tested the system for different values of the transmission ranges from 100m to 300m. The result shows that, as the transmission range increases the time needed to detect the vehicular nodes decreases and all the vehicles are tracked successfully by the system within 40 seconds.

2. *Estimation of Vehicular Density*: For computing the vehicular density, we have considered a simulation scenario with 100 vehicular nodes and 10 RSUs. The transmission range was varied between 100m to

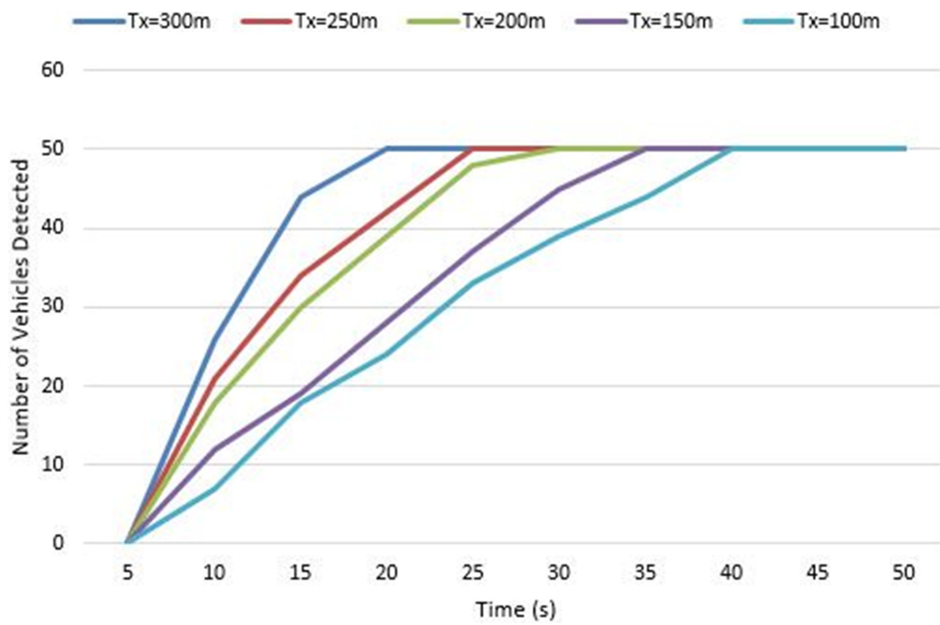

Figure 4: Vehicles Detected by the RSU Vs Time (s) for different Transmission range

300m and the other parameters are set as per the values given in Table II. Figure 5 shows the variation of local density of the vehicles for under a particular RSU with time. The actual density was calculated from the simulation environment and a comparison was made with the estimated local density. The plot shows that, the estimated values of the local density lie very close to the actual values which shows the efficiency of the proposed system.

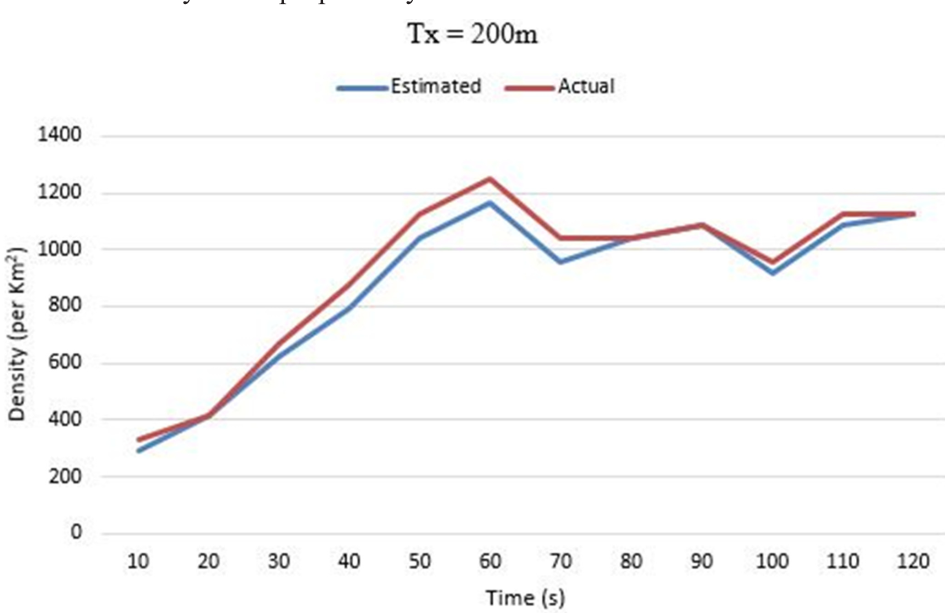

Figure 5: Variation of local density with time for transmission range of 200m

As we compared the estimated values of the vehicular density with the actual values, we computed the error in the estimation as,

$$\text{Error rate} = \frac{|D_{actual} - D_{estimated}|}{D_{actual}}$$

The error rate in estimating the local density for different transmission ranges is shown in Figure 6. The proposed system was able to estimate the local density with a higher degree of accuracy with increasing transmission range which can be visualised from the plot.

The global density of vehicles on a road segment was also computed by the system and was compared with the actual value. The error rates were calculated for different values of transmission range which is shown in Figure 7. The result shows that, the system effectively estimated the global density of the vehicles with absolute accuracy.

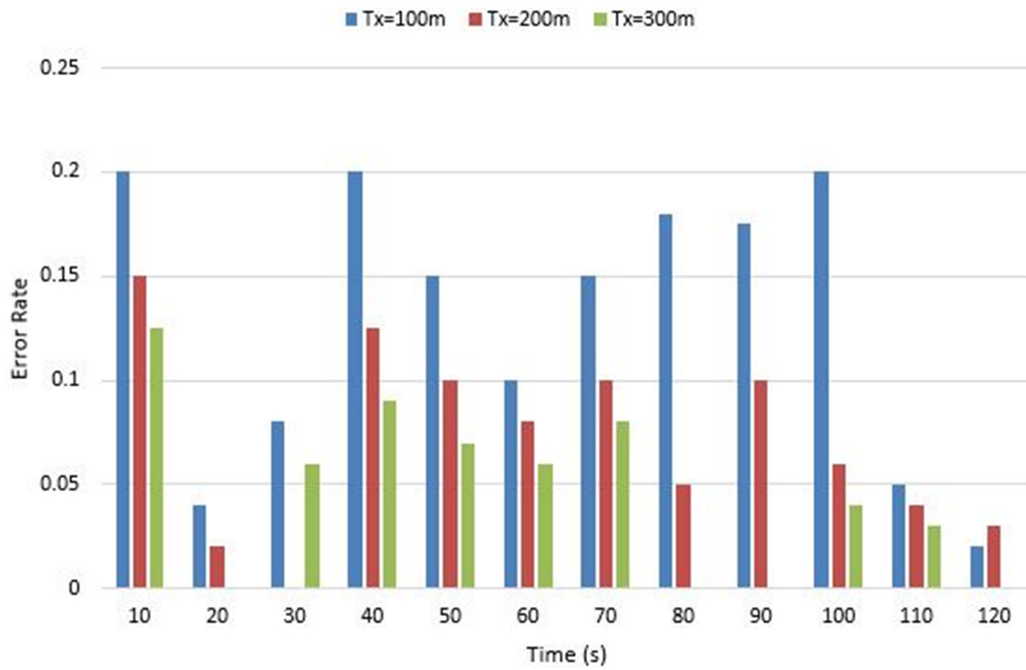

Figure 6: Error in the estimation of Local Density for different transmission range

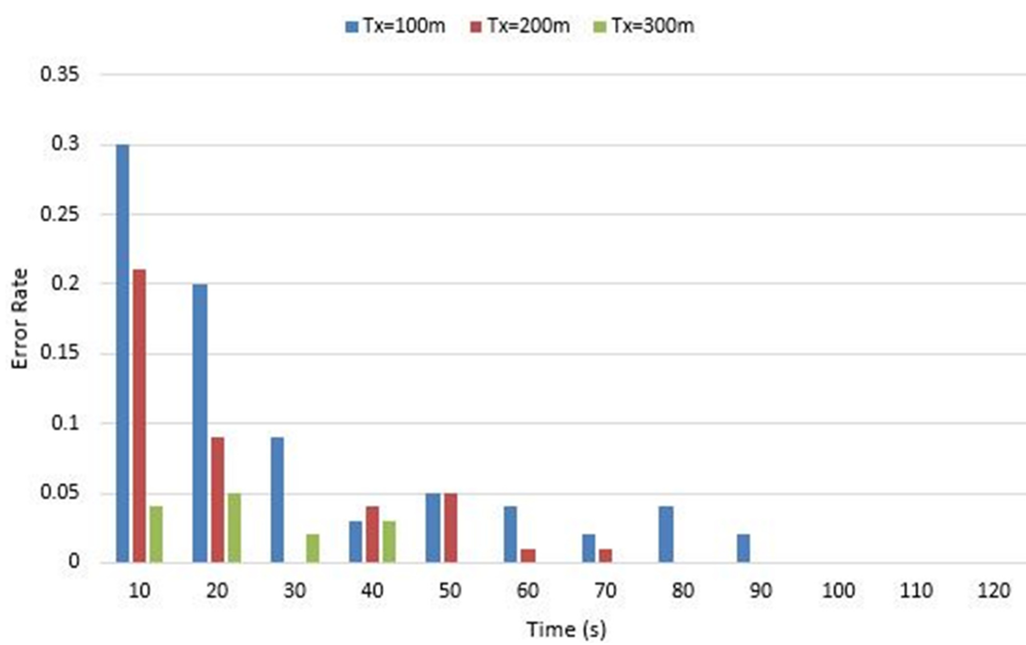

Figure 7: Error in the estimation of Global Density for different transmission range

5. CONCLUSION

Application of Information and Communication Technology (ICT) in vehicular networks to achieve various functionalities such as vehicle tracking, monitoring, navigation, road safety is gaining more popularity than ever. In this work, we have proposed an interactive communication system for tracking and congestion control in smart and connected vehicles. A hybrid architecture combining VANETs and WSN was adapted. We proposed a formulation to calculate the vehicular density on the roads. The proposed system was tested by extensive simulation using Cooja and experimental results were obtained. The analysis of the results show the effectiveness and accuracy of the proposed system. We can extend the proposed system further by considering other parameters such as the speed of the vehicles to make an approximation on the future density of the vehicles. The proposed system can also be tested with different VANET routing techniques to analyze the performance.

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