Vehicular Networks Smart Connectivity

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***Abstract*—Good connectivity helps in reducing the number of packet drop and improve network efficiency. Vehicular networks have a pattern of flow and a defined heading. Connectivity break occurs due to insufficient radio range. Dynamic coverage modulation varies the range to maintain coverage. In areas of high vehicle traffic, data packet loss would increase due to packet collision. To avoid this the coverage of node could be reduced and data handoff would be activated for maintaining connectivity. Shorter coverage in dense areas allows multiple nodes to communicate with minimal interference. Unnecessary transmissions lead to network congestion, adaptive sampling collects route information to determine its suitability for establishing communication. This work attempts at minimizing network congestion and reduce breaks in connectivity through dynamically modulated coverage, direction dependent data handoff and adaptive sampling. The algorithm has been simulated using OPNET and results reflect reduced packet drop.**

Keywords-Adaptive connectivity; Data Handoff; Dynamic coverage modulation; Adaptive sampling.

I. INTRODUCTION

Vehicular networks or VANETs are networks in which vehicles communicate with each other to disseminate vital information regarding the vehicle and traffic. This includes vehicle malfunctions, closed lanes, speed limits, accidents, caution measures due to varying driving conditions and others. These networks aim at making roads safer by warning the drivers of any potential hazards on the road.

Data dissemination in the network depend on vehicles heading, and the density of vehicles in a given region. The heading of the vehicle as shown in Figure 1 is used to determine the suitability of the vehicle to receive and/or carry forward data. For example, if lane is closed for north bound traffic due to road work, the traffic traveling on the opposite lane (south bound) would carry the information. This in turn will pass it on to the north flowing traffic. The other capability available in vehicles these days is a predefined route to the destination accessed through GPS (global positioning system). Using this information, the vehicles heading can be predicted and information can be shared.

Communication in vehicular networks as discussed in [1], [2] takes place in the following manner.

- Vehicle to Vehicle (V2V)
- Vehicle to Infrastructure (V2I)

Information broadcast and repetitive data transmission lead to network congestion and increase collision. Leontiadis and Mascolo [3] propose time to live to expunge information from the network after certain duration of time in a specific area. The issue with this is determination of the time as it is scenario specific. It is dependent on traffic movement, if the traffic is moving slow the information would also need to live for a longer duration. On the other hand faster traffic requires shorter life cycle for the data. We propose route dependent and priority based time to live. This approach for determining the life cycle of data classifies different road hazards by the level of severity and assigning priority [4]. Zhao and Cao [5] use multihop to transmit data for sparse networks. The issue with the approach is that if data is not completely transferred, while the vehicle changes its heading, and deviates from the predicted path, the data would get lost.

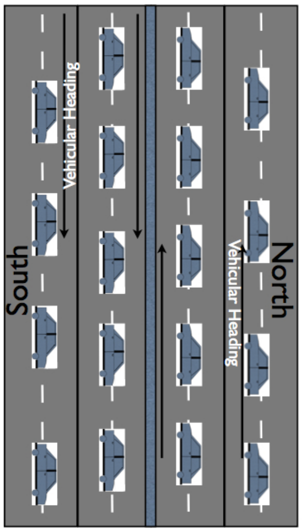


Figure 1. Definite Headings of Vehicles

Limiting the life cycle of high priority data in dense slow moving traffic does not serve the purpose. Hence, we propose modulating the radio coverage of the transmitter so that radio pollution is contained reducing communication collisions and packet retransmissions. Modulation of radio coverage would allow for reducing the coverage in dense traffic and increase coverage in places of light traffic. Radio signals are also associated with a given maximum range. Moreover, the dynamics of the roads keep changing. It is therefore required to have data handoff to transfer large data packets over multiple nodes (vehicles). Multiple hop and data handoff both require multiple nodes but in data handoff communication set-up is only done once with the first receiving vehicle. The first receiving vehicle provides the details of the transmitting vehicle to the next receiving vehicle. This approach does not require setting up the communication with other receiving vehicles. This scheme has importance in scenarios where traffic on a lane is moving fast and on the other lane the traffic is slow as shown in Figure 2a.

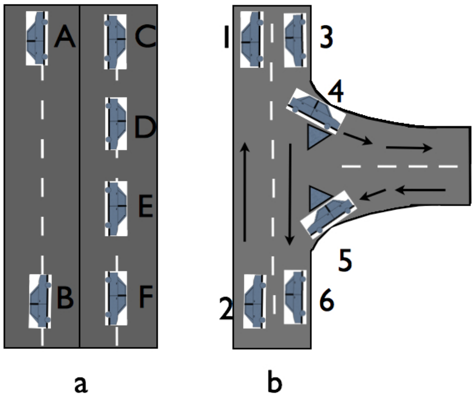


Figure 2. Traffic Scenario

The vehicles moving fast have a shorter time span to complete a communication. With large data packets the possibility of incomplete data transfers is high. To overcome this issue, if vehicle A (Figure 2a) handsoff data to vehicles F,E,D and C (in this order), the communication window of time gets wider, allowing for data packet to be successfully delivered. Figure 2b shows a scenario where direction of motion of the vehicle changes. As vehicle 4 in Figure 2b changes the path, data transmitted by vehicle 1 and 2 is not of any relevance, where as vehicle 5 is joining the lane and hence would need the information. Incorporating dependence of direction on handoff would reduce the re-transmission, thereby reducing packet collisions.

The paper is organized in the following sections. Section II discusses the effect of different parameters on vehicular connectivity. Section III gives the design for improving connectivity through handoff. Results are discussed in Section IV. Section V concludes the paper.

II. FACTORS AFFECTING VEHICULAR CONNECTIVITY

Connectivity amongst vehicles gets affected by multiple factors like vehicle velocity, transmission range, vehicle heading and route to destination.

A. Vehicle velocity

Velocity of a vehicle has a direct impact on the number of packets transmitted. At high velocities, the transmission time window reduces, which reduces the number of packets delivered. Assuming that the communication is specified by a packet size of x bytes and a bandwidth of B bps, then the required transmission time would be $T_{trans} = x/B$. For a vehicle moving at velocity v km/hr or $v/3.6$ m/s, the time required to cover a distance $d/1000$m is given as $T_{req} = d/v$. As communication takes place between two or more vehicles, hence their relative velocities are considered. For vehicle having the same heading (moving in parallel to each other) $v = v_1 - v_2$ and vehicle moving in opposite direction as shown in Figure 3, its $v = v_1 + v_2$. The communication is successful if $T_{trans} = T_{req}$, as this would allow complete packets to be delivered. Figure 4 shows that as the relative velocity of the vehicles increase, the amount of data packets received drops.

Figure 3. Effect of Velocity dependent on heading

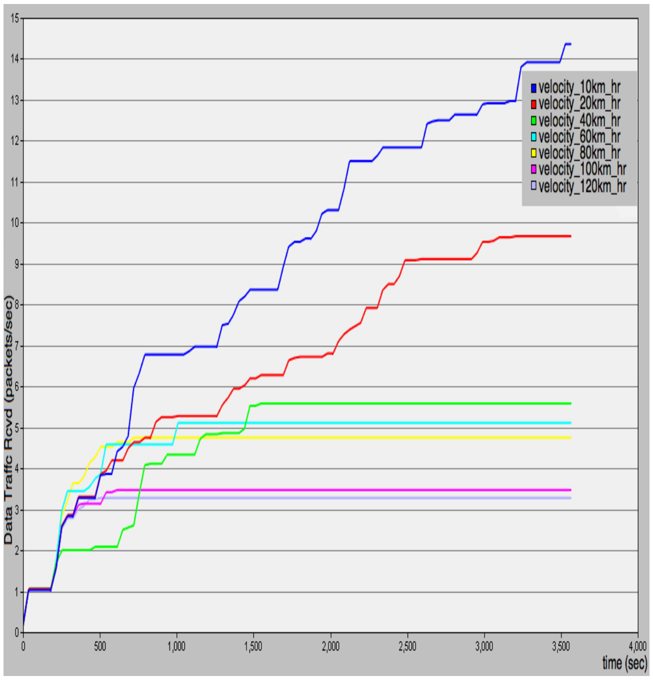


Figure 4. Available window of time for data communication against vehicle velocity

B. Transmission range

Invariably, vehicle velocity keeps changing with changing driving conditions. There are areas where vehicles move slowly and traffic builds up creating a dense network of communicating objects. Somewhere else, the traffic may be free flowing and the network becomes sparse in communicating objects. Modulating the communication range through transmission power relative to the speed will help in keeping the window of required time constant.

C. Vehicle heading and route to destination

The heading of a vehicle plays an important role in determining the suitability of a vehicle to participate in communication. If in a heavy traffic zone all vehicle start broadcasting information there would be enormous data packet collisions resulting in failed communication. Most vehicles are equipped with GPS these days. These devices pre-calculate the route to the destination. Sharing this information with neighboring vehicles would help them decide if they have any vital information that needs to be shared. Even though GPS is so prevalent, but many drivers do not always rely on them due to their personal preferences [6]. Heading of the vehicle which depends on streets and lanes allows other vehicle to determine its suitability for data handoff. The uncertainty due to human involvement can be mitigated by coupling GPS information with the current heading for handoff. If a vehicle with which handoff has been performed, changes its heading suddenly, then it would necessitate retransmission, which is undesirable. The dynamics on the road is stochastic and Poisson's distribution can be used to find the probability of retransmission.
$P = \frac{e^{-\lambda}\lambda^k}{k!}\,(k = 0, 1, 2, 3...)$
$\lambda =$ traffic density $\rho * a$(area)

$$P = \frac{e^{-\rho a}\rho a^k}{k!} \tag{1}$$

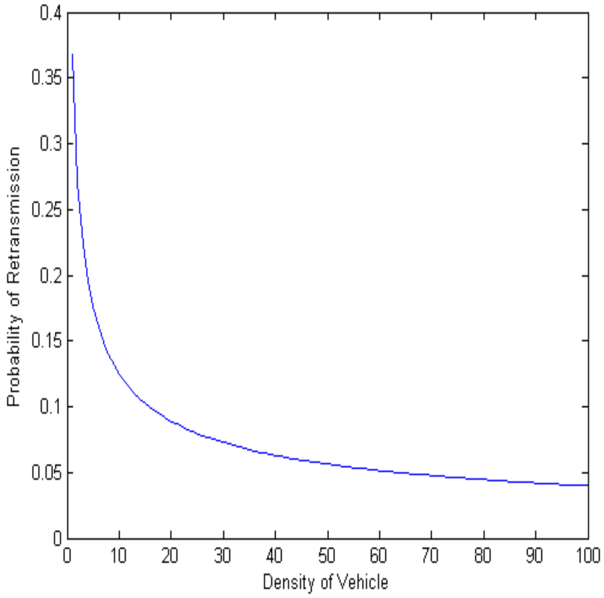


Figure 5. Probability of retransmission

It can be inferred from the probability analysis, as shown in Figure 5, that the probability of retransmission is higher for areas where vehicle density is sparse as compared to high density areas. This is because the redundancy for handoff is higher in dense areas and therefore requirement of retransmission reduces.

D. Time to Live for Data Packets

Time to Live or TTL of a data packet is used to determine the length of time for which a data packet should remain in the network (with data packet being transmitted from one node (vehicle) to another). The issue is determining how long a data packet should be present before removing it from the network as setting a random value might remove the packet either too early or congest the network with redundant data. This work proposes to adapt the time to live based on the information priority $I_{priority}$, vehicle velocity v and route $GPS_{coordinates}$ as $TTL(I_{priority}, v, GPS_{coordinates})$.

III. DESIGN FOR IMPROVING CONNECTIVITY THROUGH DIRECTION BASED HANDOFF

The different factors in Section II contribute to maintaining connectivity. Based on these, the transmission coverage, requirements of handoff and TTL of data depend on independent factors like velocity, data size, vehicle heading and route information. The flow diagram in Figure 6 shows the trigger conditions for Coverage, Handoff, Direction and Adaptive Sampling (finding new vehicles to establish communication).

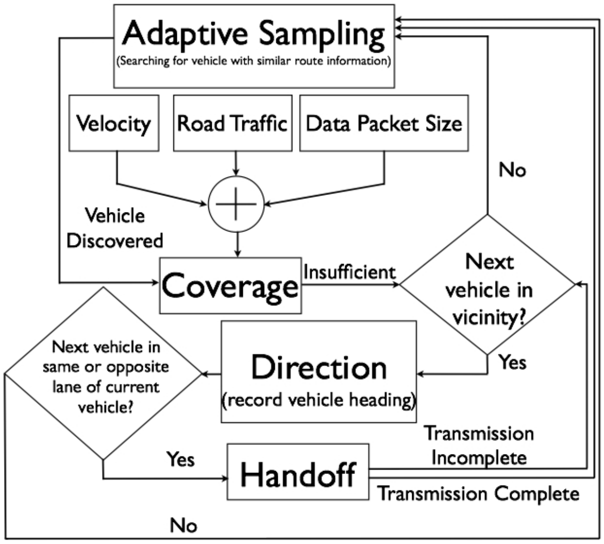


Figure 6. Flow Diagram for Connectivity of Vehicular Networks

1) Adaptive Sampling: Adaptive Sampling uses sensing coverage sense vehicles in the vicinity and exchange route information. It helps the vehicle wishing to transmit data to determine whether the other vehicle will move on the route for which the information is pertaining. If the vehicle is not following the route, then establishing the communication will be wasted. As sensing coverage also involves communication which results in use of radio resources, it should not be performed very often as it contributes to network congestion. When a vehicle has information pertaining to a particular area then it needs to know the possibility of the current route being used to reach that destination. Adaptive sampling helps in achieving this through the use of artificial neural network. It uses the past sensing information to predict the use of the current route to reach the area of interest. Depending on the outcome of the neural network the vehicle performs sampling using adaptive coverage. This reduces the sensing operation, minimizing use of radio and therefore reducing network congestion. Figure 7 shows the block diagram for adaptive sampling of the network to search for vehicles for data transmission.

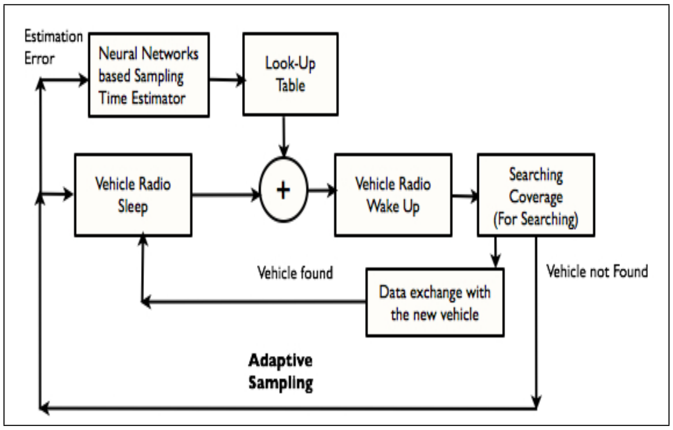
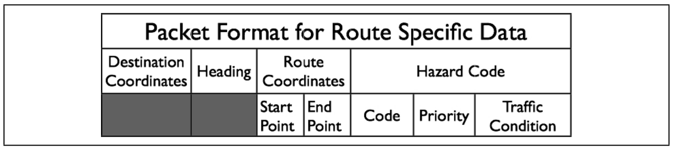


Figure 7. Adaptive Sampling for Vehicle selection

Figure 8 shows the packet format for the sensing operation. This reflects the key factors like destination, heading, route (start and end coordinates) and Hazard code (code, priority and traffic condition). The route coordinates give the start and end coordinates of the current route till the next intersection. It is not sufficient by itself because a driver may suddenly take a different route of their preference to the destination. It is therefore necessary to know the current heading and destination. As there can be multiple paths leading to the same destination, the vehicles heading will allow the determination of future coordinates. This is based on the use of current coordinates and heading to determine the route to destination. Route coordinates provide current information which would be important for the other vehicles. From Figure 7, it can be noted that artificial neural network estimates T_n (duration after which next sampling should be performed). In applications like VANETS assuming a constant traffic flow on the road would be unrealistic. For such circumstances, a single prediction of T_n would not be accurate. Hence, the output of the neural network is stored in a look-up table with possible values. When an estimation error is reported, a different value is taken from the table. The network re-trains once the values in the table are exhausted.



Packet Format for Route Specific Data

Destination Coordinates	Heading	Route Coordinates		Hazard Code		
▨	▨	Start Point	End Point	Code	Priority	Traffic Condition

Figure 8. Packet Format for Vehicle selection

2) Adaptive Coverage: Constant radius of coverage does not provide the flexibility to selectively disseminate data to other vehicles. Adaptive coverage varies according to the density of vehicles on the road. For sparse density of vehicles, the coverage increases and reduces where density of vehicles is high. The advantage of this scheme is that it reduces packet drop and network congestion.

$$R_{\max} \; = \frac{(v \cdot T_{trans})}{2} \tag{2}$$

Here, R_{max} is the maximum radius of coverage at relative velocity v. On equating Equation 2 with the range equation (Equation 3)

$$R_{\max} = \sqrt{\frac{P_t G_t G_r \lambda^2}{(4\pi)^2 \, \mathrm{S}_{\min}}} \tag{3}$$

transmission power P_t is computed and the range is dynamically varied. Here G_t, G_r are transmitter and receiver gain respectively, λ is the wavelength and S_{min} is the receiver sensitivity. The algorithm for adaptive coverage is as follows.

Table I gives the algorithm used to determine nodes coverage.

Table I: Algorithm for Sufficiency of Coverage

Algorithm for Sufficiency of Coverage
: Sense the density of vehicle in the vicinity : Compute data size to be transmitted : Compute duration of connectivity T_{trans} : Sense Vehicle velocity

3) Direction: The direction or heading of the vehicle helps predict the future route of the vehicle. Figure 9 a,b,c and d show different routes between the same source and destination. Upto point A, all the four routes are same; after point A, the route remains same for Figure 9 a and d, but for b and c the heading changes.

Similarly, at point B, the route is same for Figure 9 a

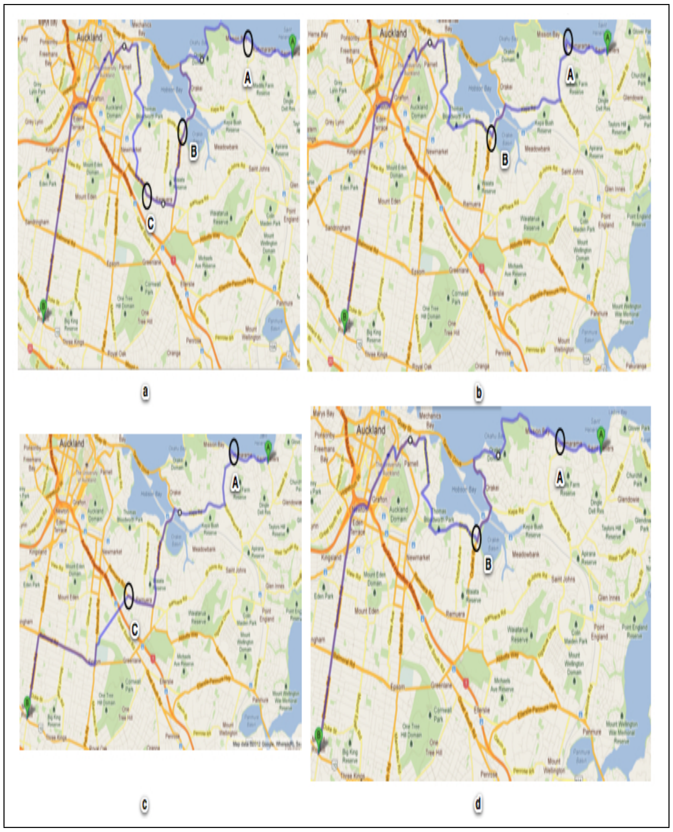


Figure 9. Vehicle heading and final destination

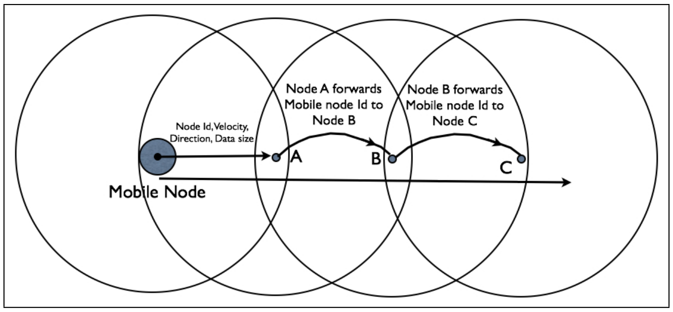


Figure 10. Handoff Scenario

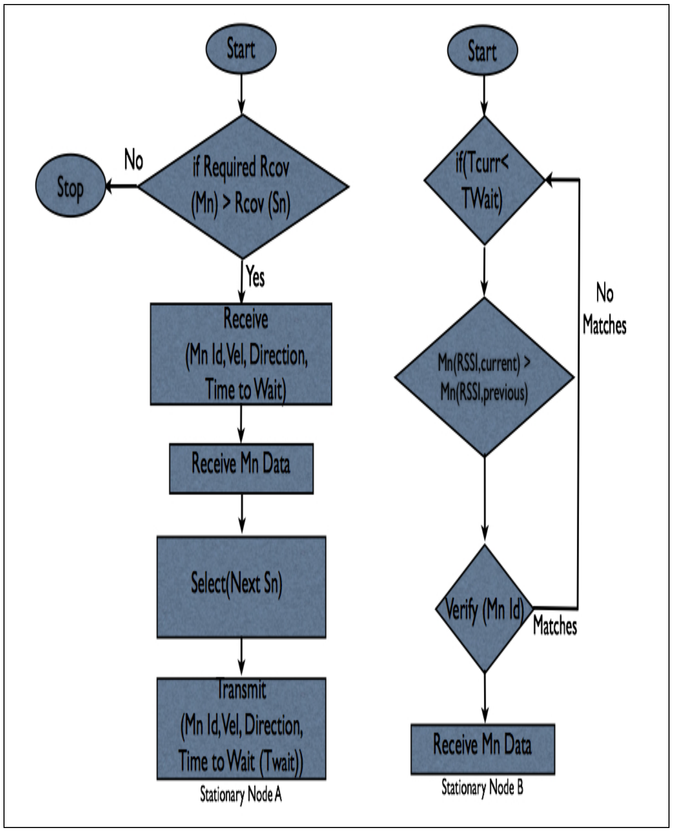


Figure 11. Handoff flow diagram

and c, whereas the heading changes for b and d. Similarly at point C heading changes between Figure 9 a and c. As destination is know the GPS device can calculate the different paths to the destination at each change in heading. If the vehicle which has some hazard information for a particular stretch of source, destination pair and the vehicle senses another vehicle heading along the same direction information handoff can take place.

4) Handoff: Handoff is required when the coverage is not sufficient because of vehicle velocity and limited coverage in high density regions. In situations like these, multiple vehicle having same heading (as relative velocity would be less for vehicles having same heading) are used to collaboratively collect the data and share amongst themselves to reconstruct it as shown in Figure 2a.

The handoff requires the vehicle transmitting V_{trans} data to transmit its Id, velocity, direction of motion, data packet size. Using this information, the vehicle receiving V_{rec} data inform their next hop vehicle about the transmitting vehicle V_{trans}, as shown in Figure 10.

As the vehicles are prepared to receive the data from the transmitting vehicle hence we save on packet exchange to establish the communication. Figure 11 shows the flow of the handoff sequence amongst receiving vehicle. The vehicle which is first to communicate with the transmitting vehicle M_n forwards its details to the next vehicle, which becomes ready to receive data from the transmitting vehicle. The Handoff flow checked by the receiving vehicle S_n checks, whether the coverage area of the transmitting vehicle is larger than its own and could data be completely transmitted. If it cannot be completely transferred, then the first receiving vehicle passes on the identification (M_nId, its velocity Vel, Direction and Time to Wait for the next node to receive data) of the transmitting vehicle to the next vehicle.

IV. RESULTS AND DISCUSSION

Network congestion happens when data traffic is not controlled. Reduction in redundant data reduces the congestion. Adaptive sampling associates route with data and determines the need to perform a transmission. Figure 12 shows the performance with and without Adaptive sampling. It is evident that the number of packets in the network has dropped leading to reduction in network congestion.

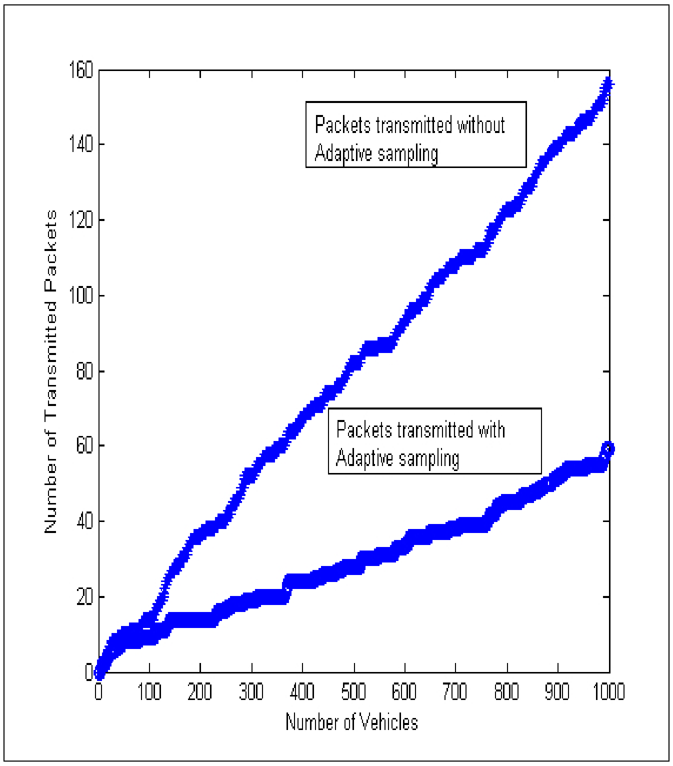


Figure 12. Number of Packets transmitted : Adaptive vs Regular sampling

Adaptive Coverage varies its coverage area depending on the traffic and the data size. Figure 13 shows that by adapting the coverage there is a reduction in the number of packets lost. The light blue and the green graphs are the number of packets transmitted and received for fixed coverage. It can be seen there is a significant packet loss. The red and the dark blue graph are for adaptive coverage. There is a significant reduction in loss of packets. In areas where the density of vehicles is less or in high density region where there is reduced coverage and a large packet needs to be transmitted, data handoff is performed to prevent break in connectivity. It's noted from OPNET simulation, Figure 14 that through handoff complete data is being transmitted over multiple vehicles, overcoming the issue of insufficiency of coverage.

Incorporating direction of motion to select a vehicle for data handoff, further reduces the unwanted data transmission. Implementing the algorithm within the nodes in OPNET shows that the vehicle which is on a lane changing its heading does not participate in communication. The result shown in Figure 15 graph 3 shows that without implementation of direction data is being received as the vehicle is

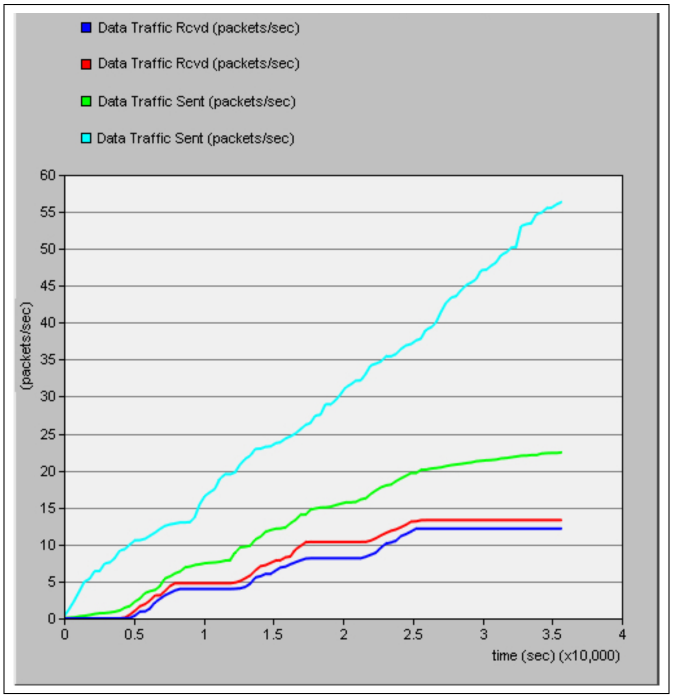


Figure 13. Comparison of Packets transmitted and packets received for Adaptive Coverage versus Fixed Coverage

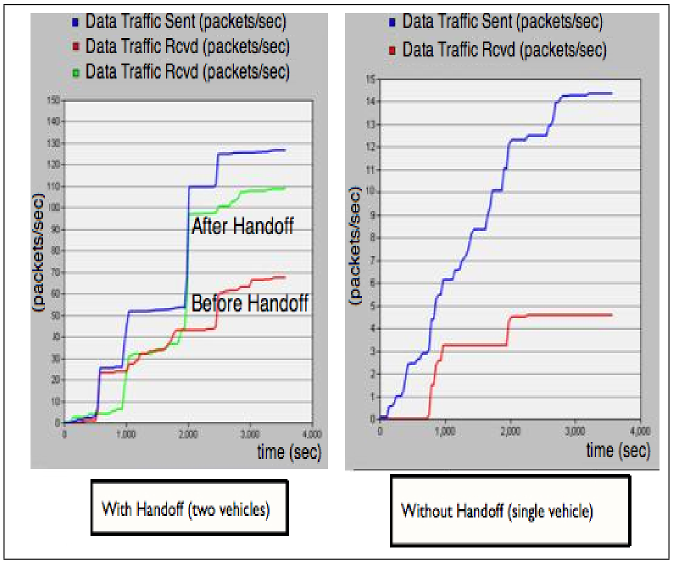


Figure 14. Comparison of Handoff with Coverage

in communication range but with the implementation of direction even though the vehicle is still in communication range but data is not received. The other vehicle graph 2 moves in a lane parallel to the transmitting vehicle graph 1 and hence receives data.

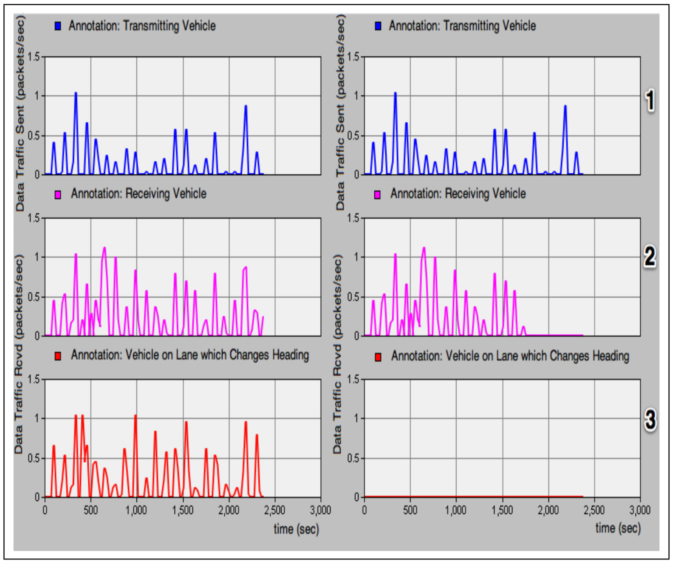


Figure 15. Direction Independent vs Direction Dependent transmissions

V. CONCLUSION

The work presented here utilizes Adaptive sampling, Adaptive coverage, Direction of motion of Vehicle and Data Handoff for intelligently sensing the need for a packet transmission. This approach reduces the number of redundant packet transmission and hence network congestion. The results show that through adaptive sampling a significant decrease in unwanted transmissions is achieved. Adaptive coverage modulates the transmission power to harness the opportunity and maintain the connectivity. It is evident from the results that in comparison to the fixed radius coverage, there is very small packet loss in adaptive coverage. Data handoff is used to maintain connectivity in scenarios where coverage is not sufficient for transmitting large data packets. Improved throughput is evident in the results. Implementation of direction allows handoff to perform selective dissemination of data. This paper shows that network congestion and packet loss is reduced through controlling the coverage radius, data dissemination and vehicular collaboration through handoff.

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