A performance Analysis of VANETs Routing Protocols Using Different Mobility Models

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Abstract—In order to evaluate a vehicular network performance it is important to develop and use mobility models that accurately capture the realistic mobility characteristics of moving vehicles. In this paper, we present performance evaluation of various routing protocols including SIFT, GPSR and GOSR using different mobility models such as Random Waypoint Model (RWM), Fluid Traffic Model (FTM) and Intelligent Driver Model with Intersection Management (IDM-IM). We present simulation results that illustrate the importance of choosing a mobility model in the simulation of a vehicular network protocol. We illustrate how the performance results considerably change as a result of changing the simulated mobility model. We show how unreliable results can be obtained by using some models such as RWM and FTM. In addition, we demonstrate how more realistic mobility models such as IDM-IM often lead to more accurate results.

Keywords-VANETs; mobility model; routing; connectivity; performance evaluation.

I. INTRODUCTION

Vehicular Ad-hoc NETworks (VANET) have recently become a popular research topic in both academia and industry. The main objective of VANETs research is to develop an inexpensive vehicular communication system to enable efficient dissemination of data for the benefit of passengers’ safety and comfort. Various efforts (e.g., ComeSafety [1], VII [2], VSC-A [3], C2C-CC [4] and InternetITS [5]), and standardization bodies (e.g., IEEE [6], and more generally ISO TC204 [7]) are currently developing a technology based on 802.11 wireless LAN. While safety is the main focus, mobile infotainment applications are expected to enhance the comfort of driving and travelling. Many infotainment applications require access to the Internet, whereas safety applications typically use direct and local communication among neighboring vehicles [8].

In VANETs, network topology and communication conditions may vary heavily (i.e., due to high node mobility), which greatly affects the network performance and making routing of data packets a complicated task. The movement of the nodes and their positions in the topology are represented by a Mobility Model which is one of the most important parameters in simulating VANETs. Using simple random-pattern, graph-constrained mobility models are a common practice among researchers working on VANETs [9]. Such models cannot describe vehicular mobility in a realistic way, since they ignore the irregular aspects of vehicular traffic. For instance, vehicles smooth acceleration and deceleration in presence of nearby vehicles since vehicles do not abruptly break and move, queuing at roads intersections as each vehicle needs to decide a turning direction at the intersection (e.g., turn left, turn right or go straight), clustering of the vehicles caused by traffic lights, and traffic congestion or traffic jams. All these situations greatly affect the network performance, since they have a big impact on network connectivity, and this makes vehicular specific performance evaluations fundamental when studying routing protocols in VANETs. A realistic mobility model should also consist of a realistic topological map which reflects different densities of roads and different categories of streets with various speed limits.

In this paper, we discuss how these details affect the network topology and thus the performance of VANET in the simulation context. We evaluate the effects of details of mobility models in VANET routing protocols simulation. Specifically, we set out to understand how the existence of traffic lights and stop signs, driver route choice and car clustering at intersections behavior may heavily affect the connectivity of VANETs, and consequently the performance of VANET network protocols. We evaluate SIFT [10], GPSR [11] and GOSR [12] in realistic urban traffic environment. In order to model vehicular motion patterns, we make use of Random Waypoint Model (RWM) [13], Fluid Traffic Model (FTM) [14] and Intelligent Driver Model with Intersection Management (IDM-IM) [15], the most widely used mobility model which are part of the VanetMobiSim [16, 17] tool. The reminder of this paper is organized as follows. In Section II, we recall some of common mobility models employed in the vehicular networking literature followed by a short description of the protocols compared in this paper in Section III. In Section IV, the effect of the adoption of different mobility models on network connectivity and end-to-end vehicle communications metrics is studied. Finally, we wrap up our analysis in Section V.

II. VEHICULAR MOBILITY MODELS

Mobility model clearly affects the simulation results. Thus, it is important to use a realistic mobility model so that results from the simulation correctly reflect the real-world performance of a VANET. Mobility models proposed for vehicular networks have been largely studied and surveyed in literature [18-21]. In the following we briefly describe the
mobility models used in this paper, more details could be found in [15].

A. Random Waypoint Model (RWM)

RWM [13] is a commonly used synthetic model for mobility. It is a simple model which describes the movement pattern of independent nodes by simple terms. According to RWM model, movement takes place within the rectangular-bounded simulation area. In this model, nodes are placed at random points of a rectangular area, picking random destinations, and then travelling there at a constant speed. As soon as a node arrived at its destination it pauses for sometimes. Afterwards, it picks a new point on the field and starts moving again. The implementation of RWM model does not consider restrictions of the spatial environment, which yields to a uniform distribution of the nodes (i.e., vehicles).

B. Fluid Traffic Model (FTM)

The FTM [14] model calculates current vehicle speed based on the total number of vehicles on the road segment. The value of minimal speed of movement corresponds to jam situations, and it must be greater than zero. This model describes the speed as a monotonically decreasing function of the vehicular density, forcing a lower bound on speed when the traffic congestion reaches a critical state [15], the influencing variables on the FTM vehicle speed are given in the following equation:

\[ s = \min \left[ s_{\text{min}}, s_{\text{max}} \left( 1 - \frac{k}{k_{\text{jam}}} \right) \right] \] (1)

where \( s \) is the output speed, \( s_{\text{min}} \) and \( s_{\text{max}} \) are the minimum and maximum speed respectively, \( k_{\text{jam}} \) is the vehicular density for which a traffic jam is detected, and \( k \) is the current vehicular density of the road the node, whose speed is being computed, is moving on. This last parameter is given by \( k = n/l \), where \( n \) is the number of cars on the road and \( l \) is the length of the road segment itself. According to this model, cars traveling on very crowded and/or very short streets are forced to slow down, possibly to the minimum speed, if the vehicular density is found to be higher than or equal to the traffic jam density. On the other hand, as less congested and/or longer roads are encountered, the speed of cars is increased towards the maximum speed value. Thus, the FTM model describes traffic congestion scenarios, but still cannot recreate queuing situations, nor can it correctly manage cars behavior in presence of road intersections. Moreover, no acceleration is considered and it can happen that a very fast vehicle enters a short/congested edge, suddenly change its speed to a very low value, which is definitely a very unrealistic situation.

C. Intelligent Driver Model with Intersection Management (IDM-IM)

This model is a macroscopic car-following model that adapts a vehicle speed according to other vehicles driving ahead, thus falling into what so-called car following models category. IDM-IM model uses a quite small set of parameters, which can be evaluated with the help of real traffic measurements. This model extends the IDM model [22], in order to include the management of intersections regulated by traffic lights and of roads with multiple lanes [15]. It borrows the car-to-car interaction description of the IDM model and provides intersection handling capabilities to vehicles driven by the IDM model. It can manage crossroads regulated by both stop signs and traffic lights. In both cases, IDM-IM only acts on the first vehicle on each road, as IDM automatically adapts the behavior of cars following the leading one. Every time a vehicle finds no intermediate car between itself and an intersection regulated by stop signs, the following variables are used by IDM-IM:

\[ s = \sigma - S \]

\[ \Delta \nu = \nu \] (2)

where \( \sigma \) is the current distance to the intersection and \( S \) is a safety margin, accounting for the gap between the center of the intersection and the point the car would actually stop at. Thus, compared to the IDM model, the distance from preceding vehicle is substituted by the distance to the point the vehicle has to stop at. On the other hand, the speed difference is set to the current speed of the car \( \nu \), so that the stop sign is seen as a still obstacle. This allows vehicles to freely accelerate when far from the next intersection, and then to smoothly decelerate as they approach a stop sign. Once a car is halted at a stop sign, it is informed by the macroscopic level description of the number of cars already waiting to cross the intersection from any of the incoming roads. If there are no other cars, the vehicle may pass. Otherwise, it has to wait until its turn in a first-arrived-first-passed and right hand rule policy. Furthermore, each time a vehicle moves towards a traffic light intersection, it is informed by the macroscopic description about the state of the semaphore. If the color is green, passage is granted and the car maintains its current speed through the intersection. If the color is red, crossing is denied and the car is forced to decelerate and stop at the road junction. Afterwards the vehicle may drive ahead or change its direction at a specific probability.

III. STUDIED ROUTING PROTOCOLS

In this section, we shortly address the three routing protocols investigated in this paper.

A. SIFT: Simple Forwarding over Trajectory

Different from previously proposed trajectory based forwarding schemes, SIFT [10] uses broadcast instead of point-to-point transmissions. Wireless transmissions are broadcast in nature and allow reaching possibly all active neighbors at the same time. Moreover, the forwarding decision is shifted from the transmitter to the receiver. Each node that receives the packet takes the decision whether to forward it or not based only on its own position, the transmitter position and the trajectory. This greatly reduces control overhead introduced by the protocol and energy consumption.

Once received a packet, each node sets a timer according to its position with respect to the trajectory and the transmitter. If a copy of the packet, forwarded by another node, is received before the timer expires, the timer is stopped and the packet is deleted from the forwarding queue. Otherwise, the packet is passed to the Medium Access Control (MAC) layer for transmission when the timer expires. Therefore, the node with the minimum timeout value will forward the packet. It is the
node in the best position since it is far from the last node and close to the trajectory. Packets include into the header the trajectory and the coordinates of the last node that forwarded the packet. The original source identifier, a sequence number, and a hop count are included as well. Each node maintains a list of recently received packets (i.e., source ID and sequence number) to avoid cycles.

B. GPSR: Greedy Perimeter Stateless Routing

GPSR [11] is one of the best known position-based protocols in literature. It combined the greedy routing with face routing by using face routing to get out of the local minimum where greedy fails. It works best in a free open space scenario with evenly distributed nodes. It is argued that geographic routing achieves better results than topology-based routing such as AODV and DSR in a highway scenario because there are fewer obstacles compared to city conditions and is fairly suited to network requirements. However, when applied it to city scenarios for VANETs, GPSR suffers from several problems [2]. Firstly, in city scenarios, greedy forwarding is often restricted because direct communications between nodes may not exist due to obstacles such as buildings and trees. Secondly, if apply first the planarized graph to build the routing topology and then run greedy or face routing on it, the routing performance will degrade, (i.e., packets need to travel a longer path with higher delays). Thirdly, mobility can also induce routing loops for face routing, and finally, sometimes packets may get forwarded to the wrong direction leading higher delays or even network partition.

C. GOSR: Geographical Opportunistic Source Routing

The GOSR [12] protocol is composed of two parts, namely geographical source route selection and geographical opportunistic forwarding. They are discussed in the following.

1) Geographical Source Route Selection

Geographical source routes are computed in an on-demand fashion. A graph is extracted from the e-map. Junctions as well as the positions of the source and destination nodes are represented as vertices and road segment between junctions are mapped as edges. Each edge is coupled with a weight, whose value is proportional to the length of the road segment. Once the graph is ready, the Dijkstra algorithm is applied to find a shortest path from the source to the destination.

2) Geographical Opportunistic Forwarding

Once the geographical source route is selected by the source node, GOSR enters the geographical opportunistic forwarding phase. The data packet of GOSR contains the following fields: a list of junction position, last hop position, best-known neighbor ID, and the scope. The value of the scope is critical for minimizing the notification cost. For this paper, we simply set the scope twice the distance between the current forwarder and its best-known neighbor as described in [12]. When receiving a packet, the node checks whether it is within the designated scope by using the last hop position and the scope information in the packet. If yes, it compares itself with the best-known neighbor. If it is closer to the next junction than the best-known neighbor, it becomes a candidate. Since there might be multiple candidates, GOSR uses defer timers to avoid simultaneous transmissions (i.e., candidates snoop the media in the defer phase). The defer time of the best-known neighbor is the maximum value and the defer time of the node at margin of the scope is 0. In this way, GOSR ensures that better forwarding opportunities are given higher priorities.

IV. PERFORMANCE EVALUATION

The impact of accurate mobility modeling on network performance can be judged by comparing results from an identical simulation scenario being fueled by different mobility models. In the following, we present selected simulations and compare results obtained using a RWM, FTM and IDM-IM models. Reflecting recent simulation results for VANET protocols based on very different mobility modeling approaches, we demonstrated how more realistic mobility models often lead to vastly different results. In this section, we evaluate the impact of mobility models generated by VanetMobiSim on the performance of VANETs routing protocols. VanetMobiSim is a freely distributed, open source vehicular mobility generator tool based on CanuMobiSim architecture [23]. The input of VanetMobiSim is an XML file where the user specifies the different mobility configurations to define the scenario to simulate. The output of VanetMobiSim is a trace file which specifies the mobility of the vehicles that have been simulated. The trace files may have different formats depending on the network simulator that will use these traces, including NS-2 [24], OPNET [25] and GloMoSim [26]. For simplicity reasons, we do not distinguish between different types of vehicles like cars or trucks in the following evaluations.

A. Simulation Setup

In this paper, we used VanetMobiSim/NS-2 [24] simulation environment in order to conduct our performance evaluation study. In all simulations, the source and destination nodes are static. GPSR and GOSR protocols exchange location packets every second (i.e., beacon interval). The propagation model employed in our simulation is the TwoRayGround model. All nodes use IEEE 802.11 MAC operating at 2 Mbps. The transmission range is 250 m. The source node sends one CBR packet per second to the destination node, and the simulation lasts for 1000 s. For all simulation results in this paper, each experiment is repeated ten times on different network topologies. Table 1 shows the parameters settings for these set of experiments.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
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<tbody>
<tr>
<td>Simulator</td>
<td>NS-2</td>
</tr>
<tr>
<td>Mobility simulator</td>
<td>VanetMobiSim</td>
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<td>Simulation time</td>
<td>1000 s</td>
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<tr>
<td>Simulation area</td>
<td>3000 x 1000 m^2</td>
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<tr>
<td>Transmission Range</td>
<td>250 m</td>
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<td>Vehicle speed</td>
<td>2 – 20 m/s</td>
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<tr>
<td>Packet rate</td>
<td>1 packet/s</td>
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<td>Node density</td>
<td>30 vehicle/km</td>
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<tr>
<td>Mobility model</td>
<td>RWM, FTM, IDM-IM</td>
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<tr>
<td>Pause time for RWM</td>
<td>60 s</td>
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</tbody>
</table>
The simulated city scenario is based on the road network topology shown in Fig. 1. In our simulated scenario, vehicles travel in a 3 km² city section over a set of urban roads, which include several road intersections regulated by traffic lights or stop signs. The roads created in the simulation have two lanes and vehicular movement occurs on a single direction in each lane.

B. Mobility Models Analysis

In the following, we report results obtained with the RWM model, which causes node to move with a constant speed over a straight trajectory towards a destination randomly selected in the square area, and then to pause for an amount of time before starts moving towards another destination. Due to its nature, this model is not bound by road constraints. Thus, it maintains a more even distribution of nodes, and thus suggests a better network connectivity. Figure 2 (a) shows the vehicle density evolution (i.e., average number of neighbor vehicle) with time. Here, we define a neighbor vehicle as a vehicle which is within the radio range of a giving vehicle. As expected, RWM model spreads nodes all over the square area leading to an unrealistically moderate mean density than FTM and IDM-IM models. Consequently, it provides a better network connectivity reflected by the low number of no route (i.e., network disconnection) depicted in Figs. 3 (a) and 4 (a).

The second mobility model used here is FTM model, which does not take into account intersection management. Thus, the average number of vehicles at crossroads does not differ from that of vehicles on roads nearby, which is definitely far from reality [15]. This fact is consistent with the results shown in Figs. 2 (b), 3 (b) and 4 (b). FTM model produces a better distribution of the vehicles across the simulated area comparing to IDM-IM model, and thus it yields to a better network connectivity.

Figures 2 (c), 3 (c) and 4 (c) show results obtained with the IDM-IM model, which is capable of managing intersection with existence of traffic lights or stop signs. In real world, traffic lights are used to regulate traffic flow moving in different directions. The existence of traffic lights tends to create a clustering effect as vehicles queue in the road junctions. In other words, places where there is a traffic light are likely to have a higher node density since vehicles are forced to stop at the traffic light to wait for the light to turn green. Naturally, a high node density might improve the network connectivity. On the other hand, a higher node density might also suggest a higher chance for packet collision since more nodes might be transmitting at the same time. The higher concentration of vehicles around intersections also has the side-effect of reducing the number of vehicles on the other roads of the topology, which, records lower vehicular densities as illustrated in Figs. 3 (c) and 4 (c), which, as a result, incurs a drop in the number of delivered packets. A realistic effect of smooth vehicular density, increasing towards the congested crossroads, is obtained with this model as depicted in Fig. 2 (c). It is apparent that density increases when the vehicles speed increases. In addition, the distance between two adjacent traffic lights can have a significant effect on the network connectivity. Specifically, the network can be fragmented by the traffic lights when the radio transmission range is smaller than the distance between two adjacent clusters. In other words, a link breakage can happen when the inter-cluster distance is larger than the radio coverage. Here, we set the distance between two adjacent intersections to 500 m, which is double the radio range.

C. Simulation results

We now discuss the influence of the chosen mobility model on the performance of the three routing protocols: SIFT, GPSR and GOSR. For this comparison, we chose to focus on FTM and IDM-IM mobility models as well as the RWM model. For analyzing the performance of the selected routing protocols we considered the following performance metrics:

- **Packet Delivery Ratio**: is the ratio between the number of packets received at the destination to the number of packets sent by the source.
- **Average Latency**: it represents the average end-to-end transmission delay by taking into account, only, the correctly received packets.
- **Data Throughput**: is the total received number of bits divided by the simulation time.

1) Speed

This experiment set involves the investigation of the impact of nodes speed on routing protocols with the average speed between 2 and 20 m/s and vehicle density fixed at 30 vehicle/km. The destination node was placed 2 km away from the source node, other settings are same as in Table 1. As shown in Figs. 5-7, GPSR and GOSR experience a drastic decrease in their performance affected by nodes speed, since their location information dissemination procedure completely depends on nodes speed. As depicted in Fig. 5, the faster nodes move, the more frequent nodes new positions must be disseminated through the network. When speed exceeds a certain value, the channel gets overloaded and transmission errors occur. When nodes speed increases delivery ratio decreases, this is consistent with the average throughput depicted in Fig. 7. It is important to note that delivery ratio in SIFT increases with speed in case of FTM model until it reaches the steady state (i.e., speed is more than 11 m/s). This is because nodes have a better (uniform) distribution when they move faster as the FTM model does not consider intersections or stop signs. In this experiments set, average end-to-end delay
remains constant as this parameter depends, merely, on network density and distances between sources and destination nodes, which are constant in this set of experiments. However, SIFT incurs high delay values in case of RWM model since nodes are placed far from the trajectory. In general, nodes speed is a parameter that has a negative impact on location table-driven routing protocols for mobile ad hoc networks because the information kept in the location table is completely linked to nodes speed. From this remark, the most important assertion that can be obtained is that SIFT performance remains completely constant in terms of speed, as shown in Figs. 8-13. This is because of the special routing technique implemented by SIFT, which is not location table-driven. As shown in Figs. 3 and 4, in this scenario we observe frequent network disconnection between two adjacent clusters when using IDM-IM model, which significantly degrades the network performance. Although, the number of disconnection between the source and destination nodes is more in the case of IDM-IM than FTM model, but surprisingly GPSR and GOSR produce a higher delivery ration in presence of IDM-IM model while SIFT produce a better delivery ratio when using FTM model. Average end-to-end delays seem consistent in all models, while it is important to note that SIFT in FTM model case experience high delay because distances between vehicles

(a) RWM model
(b) FTM model
(c) IDM-IM model

Figure 2. Average number of neighbor vehicles vs. time.

(a) RWM model
(b) FTM model
(c) IDM-IM model

Figure 3. Total number of no routes vs. time.

(a) RWM model
(b) FTM model
(c) IDM-IM model

Figure 4. Total number of no routes vs. time.
and the trajectory are longer since RWM model is not bound to the road constraints. In the case of RWM model, all routing protocols perform considerably better than when the FTM and IDM-IM models are used.

1) Distance
The second experiment set involves the investigation of the impact of distance between the source and destination nodes on routing protocols when vehicle density is fixed at 30 vehicle/km. We varied the distance between the source and destination nodes from 500 to 3000 m. For all other nodes the average speed is 10 m/s. Simulation results are presented in Figs. 8-10. Figure 8 shows the packet delivery ratio as a function of distance. It is apparent that for all protocols with all different mobility models used the delivery ratio actually decreases as the path length increases since an increased number of hops increases the probability to lose packets. This effect is due to the fact that the probability of finding a low-connectivity zone in the network is proportional to the number
of intermediate nodes that forward the data packet. This is consistent with the average throughput depicted in Fig. 10. Figure 9 shows the average end-to-end delay incurs by RWM, FTM and IDM-IM models. It is clear that all the routing protocols experience an increase in the delay when the distance between the source and destination nodes increased as the number of hops in the path also increased resulting in more delays to deliver packets to their destination node. Again, SIFT incurs high delay in case of RWM model for the same reason indicated above. Despite the clustering effect produced by IDM-IM model, it still delivers more packets to the destination than FTM model when varying vehicles speeds. While, FTM model outperforms IDM-IM model in terms of number of successfully delivered packets when varying the distance between the source and destination nodes, the longer distance increases the probability of encountering network disconnection, and thus increases the number of dropped packets. It is important to highlight that all protocols consistently perform better in case of RWM model than in the case of the FTM and IDM-IM models. This is because the
uniform distribution of vehicles produced by this model, which provides an adequate connectivity (see Figs. 2-4). The RWM model considerably overestimates the performance of the routing protocols that we used for our evaluation. We can conclude from our results that care should be taken if simple mobility models (i.e., RWM and FTM models) are used for the evaluation of vehicular networks as the results obtained with these models might not be as close to reality as expected.

We can say that SIFT depicted the best performance in the simulated scenarios. Its mechanism of dynamic selection of relays causes the lowest overhead, which equals to zero. Moreover, it has the highest throughput and is able to deliver packets quite fast. SIFT is followed by GPSR, which has a lower throughput than SIFT, but also reaches good results and delivers packets faster than in SIFT while GOSR not only suffers from a high number of dropped packets but also from a high delay in our simulations. This is because of the retransmission timer policy used; it enforces each node to delay its transmission for a period of time to reduce contention. Both the criteria and retransmit delay are calculated in quite simple ways without deep analysis.

V. CONCLUSIONS

The performance measures of VANETs routing protocols are directly affected by the underlying mobility model used. This paper’s results highlight our belief that simulation studies should be undertaken in with great caution. We can state that much remain to be done to ensure that mobility models accurately capture our expectations of how mobile nodes actually move. Our findings show that the RWM and FTM models fail to provide a realistic movement pattern. Consequently, the use of these models can result in misleading or incorrect conclusions, and thus they cannot be applied to all simulations of vehicular networks urban scenarios. While, the IDM-IM model proved to be more realistic as it is capable of modelling detailed vehicular movements in different traffic conditions. In this paper, we have evaluated the performance of SIFT, GPSR and GOSR in vehicular ad hoc networks urban environments. These performance evaluations are important to improve the routing efficiency in urban vehicular networks environment. We have tested the protocols against node speed and distance between the source and destination nodes. We found that SIFT outperforms both GPSR and GOSR for most of the performance metrics we used in this paper. The results showed that the nodes speed has a significant influence on the location based routing protocols performance. An important observation was that the examined routing protocols depict highly heterogeneous performance results under different mobility model. From the results obtained in this paper, it appears clear that the differences observed between different mobility models, in terms of vehicles distribution, and presence of clusters have a significant impact on the network connectivity, and consequently the performance of VANETs protocols. We argue that a realistic mobility model is critical for accurate network simulation results. Also, one of the most important parameters in simulating VANETs is the radio propagation model. Simulation studies that do not account for the influence of physical obstacles (e.g., buildings, trees, long cars, etc.) on radio signal propagation can almost not be realistic, and this will be our future focus.

REFERENCES