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FIRMS: A Framework for Intelligent Road Monitoring System using Smart Sensors

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Abstract– **We introduce a novel system to monitor traffic using deployed nodes placed uniformly on the highway to monitor the road traffic. We take advantage of the Cat eye's on the road by adding sensing capability (metal detectors) with embedded processors, the sensing feature provides an accurate detection of the average number of vehicles and its average speed on the highway using an aggregation function. The main goal of the proposed system is to monitor the traffic flow on the highways and to provide drivers with safety notifications messages. In our system, we calculate the size of clustering and communication timing between nodes. For power consumption, our system implements two concepts: converting solar light to power in conjunction with a sleep/awake mode of operation. We can reach a power life of at least one year before maintenance might be required. Our simulation calculates the cluster size between nodes in different modes of operations. Our model gives an intelligent road system to highways. The main advantages of our system are its low cost, easy of deployment and reduced maintenance.**

Keyword: Vehicular Networks, Information Propagation, VANET, Sensors, traffic incidents.

1. Introduction

Vehicular Networks is one of the hot research areas these days. Two combinations of communication have been used in the Vehicle Ad-hoc Networks (VANET) field, Vehicle-to-Vehicle (V2V) and Vehicle-to-infrastructure (V2I). The main focus of researcher is to invent a new technology without expensive changes in the infrastructure. Cat's eyes - which are built in the road as reflectors that can help drivers to see the road in the fog condition or at night - can be used in the VANET technology. We add sensing capability to each node of Cat's eye in order to create an Ad-hoc Network that won't suffer from any network disconnection problem [1]. As traffic incidents are considered one of the major factors leading to traffic jams; there is a crucial need to develop a system that helps reduces those road incidents. The proposed system will notify the drivers as early as possible of any risk or danger ahead. That gives the ability and the sufficient data to make balanced and intelligent decision about these risks [2]. Numerous architectures require an unrealistically expensive deployment and maintenance cost or cannot be converted to Highways [3]. Therefore, our proposed approach introduces a cost effective framework for monitoring the highway and in the same time incident notifications.

The remainder of the paper is organized as follows. In Section 2, we discuss the main idea and related work. Our proposed model is discussed in details in Section 3. Model analysis is done in Section 4. Our simulation comes in Section 5. Then, we discuss different applications in 6. Finally, Section 7 is our conclusion and future work.

2. Main Idea and Related Work

2.1. Main Idea

On highways, Cat's eyes are placed along the road on both sides. A metal detector sensor is placed inside each cat's eye. These nodes (the cat's eye) form a network to disseminate the information about average speed and density (number of vehicles/ time period) to the other nodes of the network. The information will be forwarded (backwards) to the other nodes on the road. There are three benefits of using the cat's eye. First, they already exist on the highways and periodically maintained. Second, the uniformly placement of the cat's eye gives the advantage of sensing the highway completely and,third, information captured from nodes can monitor the car density on the highway; detect an incident, forward emergency information or alert weather conditions on the highways to drivers.

2.2. Related Work

Abuelela et al [3] propose a secure architecture for notification of traffic incidents. Their idea is to build sensor belts in the road every specific interval while avoiding the heavy cost of optical fiber that has been used in Inductive Loop Detectors (ILD). They dig a belt on the road every couple of miles which will cost lots of money for maintaining the system. Also, they depend on vehicles to forward their message which cannot be done with sparse traffic highway. Also, they cannot solve the problem of blocking incidents. Moreover, they depend on the behavior of vehicles on the road which is unrealistic in some cases.

Karpiriski et al [4] describe the use of Cat's eye in a single road; they didn't explain any details on how the nodes will communicate or the model details. They just mention the services

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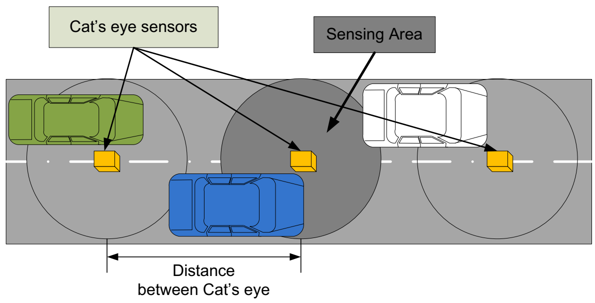

Fig. 1. A Group of sensors on the highway. Cars are detected in the sensing areas.The figure is not drawn to scale.

that can offered from Cat's eye implementation. Weigle et al [5] described enhancement to benefit in large-scale evacuation situation. Also, a similar idea of placing sensors in the road surface has been employed which manufactures devices called road studs. They are equipped with light, humidity, and temperature sensors and also with a number of bright LEDs that change color depending on the weather conditions sensed by the sensors. However, there is no communication between the devices so they are not considered to be a sensor network [6].

Most developed techniques are using inductive loop detectors (ILDs) which are already installed at regular spacing along the freeways. On the other hand, Wimmer et al [7] are building a mapping system for the road constructions using sensors that is built above the road in a signal light or infrastructure beside the road.

3. Proposed Model

Not only our goal is to monitor the road but also to notify drivers of any accident or bad weather conditions. Our idea depends on the nodes placed on the road that allows propagating data (backward and forward). We assume that each node contains a metal detector sensor that measures [8] the existence of metal in the surrounding area. The metal detector is a waterproof detector that can use radio direction-finding technology to detect the existence of a metal. Any node in our system can report its own readings and measurement. These nodes can report such information such as geographic position, the period a vehicle spent in its sensing area, intensity of metal (small vehicle,Truck,trailer , ..etc). Over a period of time T, sensor S_i has stored data about the average number of vehicles A_i and the average speed v_i as shown in 1.

3.1. Locality of nodes

Let S_1,S_2,S_3,...S_i...S_n group of consecutive nodes on the highway. The distance between two consecutive nodes on the highway is known as d. This distance is pre-defined in each state-in Virginia, USA it is (80 feet) 24.3 meters -[9]. Each node is sensing the area around it with radius of 4 meters which covers a circle around the node. Nodes can communicate with each other which is described later in 4. we define the locality of nodes as recording the same parameters or data over a given distance. Referring to figure 2, in case of normal density traffic or sparse with no incidents, sensors from S_1 to S_j where $j < i$ record the same

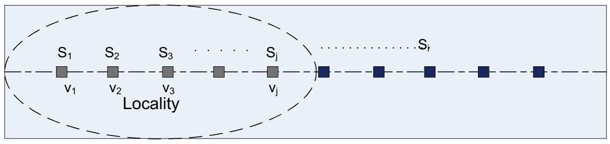

Fig. 2. A group of sensorsS_1,S_2,S_3,...S_j with the same average speed and density is gathered in same cluster

value of average speed and average number of vehicles which we call *locality of nodes*. This feature allows the system to save power as described later in section 4. The area surrounding the nodes from S_1 to S_j is called *Dynamic Cluster*.

3.2. Dynamic Cluster

Dynamic Cluster is the called on a group of sensors that have same values for average speed v_i and average number of vehicles per time period A_i . As traffic starts to slow down or an incident occurs. Some sensors will detect a change in the current status of values for average speed and average density. The dynamically changing allows the cluster to decrease in size, increasing and decreasing of size of group of nodes is called this feature "Dynamic Clustering" as shown in figure 2.

3.3. Power Consumption

Power consumption is one of the most critical and important issues in wireless sensor networks. Typical wireless sensor networks uses batteries with a limited capacity [10]. Currently, new technology offers a wireless transmitter that transmit up to 180 m , 64-Bit Unique ID , up to 100 sensors can coexist and with battery life of two years [11]. Our model uses a wireless transmitter system that has a metal detector sensor that senses vehicles and produces dynamic signals representing the sensed parameters [12]. We assume a power supply consisting of a rechargeable battery with a mini solar panel connected to a lead acid battery. Moreover, using a sleep/wake up mode that allows saving power consumption. Since speed of vehicles in normal cases does not change so much, then the sleep/wake up mode can be used in our model. The concept of Dynamic Cluster allows the system to save power by giving the nodes in a cluster the chance to sleep and save its own power. This can be done by allowing the first and last sensor in a given cluster to notify middle sensors to go to sleep.It is contemplated that in the near future the sensors will energy self-sufficient as they will be able to recharge energy from vibration induced by passing vehicles.

3.4. Sensors Synchronization and Communications

Sensors need to communicate with each other whenever there is a change in traffic flow on the highway (low speed and high density). Each sensor has a cycle life of period T. The cycle is divided into two parts. First part is the sensing period , where the sensor senses the surrounding area and calculate the average speed and average density at that period. Second part is the communication period where information is sent - if necessary - to neighbors to inform them with a change in speed or an incident. As shown in figure 4.

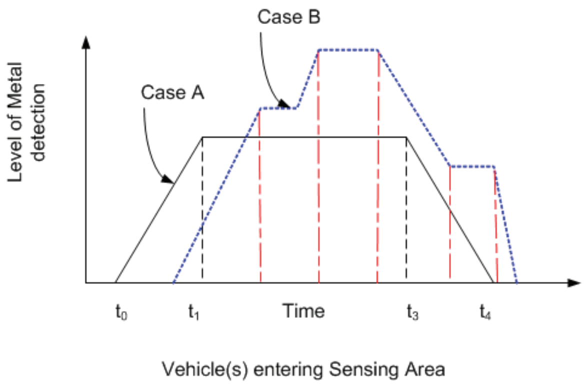

Fig. 3. Speed calculation from metal detection level

4. Model Analysis

4.1. Speed Calculation & Density

In order to calculate the average speed surrounding a sensing area; assume a vehicle approaches sensor S_1, values of metal detection are recorded at time t_1. Using the level of metal detection and the time of entering and leaving the area of sensing, speed can be calculated. Figure 3 shows how metal detection level will change depending on the level of metal in the sensing area.

Algorithm 1 Sensor update status

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procedure UPDATE-STATUS($V_1(t_1,\upsilon_1,\mu_1)$,$V_2(t_2,\upsilon_2,\mu_2)$)
  define threshold value,T_y,υ_y,μ_y;
  while $NotSleep$ **do**
    if $\upsilon_2 - \upsilon_1 > \upsilon_y$ & $\mu_2 - \mu_1 < \mu_y$ **then**
      Traffic getting faster and less vehicles Status = Faster flow;
      if $\upsilon_1 - \upsilon_2 > \upsilon_y$ & $\mu_1 - \mu_2 < \mu_y$ **then**
        Traffic getting slower and more vehicles Status = Slower flow;
      else
        Status= No change;
      end if
    end if
  end while
end procedure

In figure 3, the sensors -using the embedded processors- can detect the entrance of a vehicle when the level of metal detection starts to indicate the existence of metal at this area. Case A shows the situation that one vehicle entering and leaving the sensing area. In this case the speed can be calculated by the time spent in the area of detection $v = diameter/time$. In case B, more than one vehicle has entered the level of sensing at different timing. Average speed can be calculated from the time the level of metal is changing.

Our goal is to detect the average speed through the cluster from the information collected in each sensor in one cluster. A vector of $v(v_1, v_2, v_3, v_4)$ can give us the calculated speed in each sensor and from these data we can get the average speed.

Algorithm 1 above shows how to update sensor information depending on data sensed and received in period of time T, we

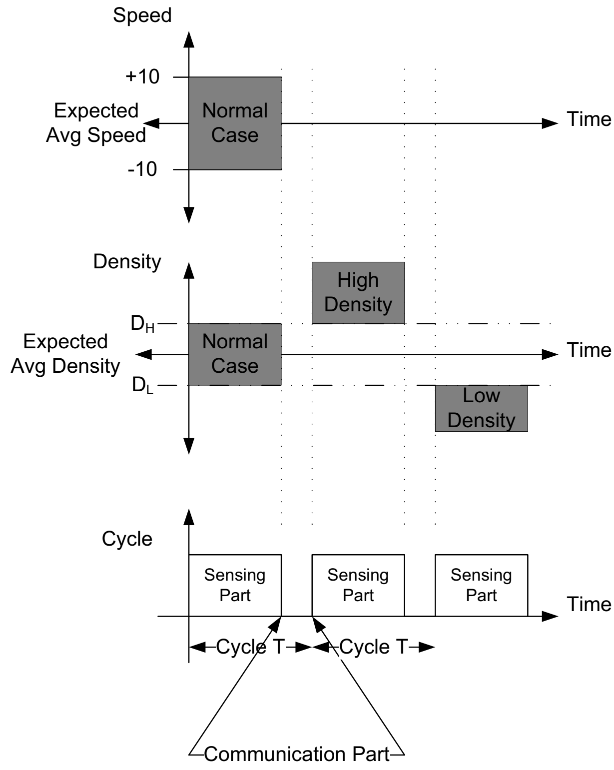

Fig. 4. Sensor Cycle - Average Speed Detection - Average Density (Number of Vehicles per cycle)

assume two vectors V_1 and V_2 with parameters (time,speed and density of vehicles (Counted number of vehicles)).

4.2. Cluster Size (number of nodes per cluster)

In order to calculate the updated value for the number of nodes in a cluster, our model will obey some rules.

- Rule 1: Whenever a sensor found a decrease in traffic flow, then cluster is in the stretching phase .
- Rule 2: Whenever a sensor found an increase in traffic flow, then cluster is in the shrinking phase or stay same size.
- Rule 3: A group of sensors in same cluster allow the middle nodes to go to sleep and save power.
- Rule 4: There is a maximum value for cluster size depending on the largest communication range can be used.
- Rule 5: No change in traffic flow for three cycles, then cluster is in the stretching phase

4.3. The expected number of vehicles that pass before turning to save mode

Now, let us assume that vehicles pass a certain sensor location according to a Poisson process with parameter λ. Before allowing the whole cluster to sleep , we wait until no vehicles will come by the next T time units. Then the expected time cluster will wait before going to saving mode(sleep) is given by:

Let X_1,X_2,...,X_n,... the car inter-arrival time. Let further, W be the random variable that counts the cars that will pass before cluster go to save mode:

$$
\begin{aligned}
Pr[W = k] =& Pr[X_1 \le T \bigcap X_2 \le T \bigcap ...X_k \le T \bigcap X_{k+1} > T] \\
=& Pr[X_1 \le T].Pr[X_2 \le T]...Pr[X_k \le T].Pr[X_{k+1} > T] \\
=& (1 - e^{-\lambda T})^k.e^{-\lambda T}
\end{aligned}
$$

Thus, the expected number of vehicles that pass before turning to save mode:

$$
\begin{aligned}
E[W] =& \sum_{k \ge 0} k.(1 - e^{-\lambda T})^k.e^{-\lambda T} \\
=& (1 - e^{-\lambda T}).e^{-\lambda T}.\sum_{k \ge 0} k.(1 - e^{-\lambda T})^{k-1} \\
=& (1 - e^{-\lambda T}).e^{-\lambda T}.e^{2\lambda T} \\
=& e^{\lambda T - 1}
\end{aligned}
$$

Finally, the expected time the cluster wait before switching: $= \frac{e^{\lambda T - 1}}{\lambda}$

5. Simulation and Evaluation

In the simulation, we compare two scenarios to trace the change in cluster size in two cases. First scenario, in a high density highway and slow traffic ; sensors are always in the awake mode and cluster size decreases, we assume that if two vehicles exist at the same area of the same node that will conclude a collision in sensing; and both messages are dropped. The second scenario, we try our model in the sleeping mode (where nodes go to sleep every couple of mins) in that case cluster size increases. In both scenarios, we don't allow vehicle-to-vehicle communication and we try to record the cluster size. Then, we have two cases,*case I*:No sleeping mode is implemented (sensors are always awake) and *case II*:Sleeping mode is implemented.

5.1. Simulation Settings

We evaluate our frame work using ONE simulator [13], which is the Opportunistic Network Environment simulator that used to generate node movement using different movement models, route messages between nodes with various routing algorithms and sender and receiver types. It allows to visualize both mobility and message passing in real time in its graphical user interface. In the simulation, our model uses a two lane highway of size 11 miles which describes a part of the Highway US-13 that goes beside the East coast from Virginia to New York. We generate vehicles randomly from the start points. The model assume a fixed stations between the two lanes which represents our nodes (Cat eye's) along the highway, we call them (Group I fixed nodes). These stations are 24.384 meters (80 feet)[9] apart from each other. Each vehicle - we call it (Group II moving nodes) broadcast a packet every 2 seconds in the range of a circle with radius 12.192 meters (40 feet). Our model calculate the cluster size in different cases.The simulation parameters and values are listed in Table I.

Figure 5 shows our simulation; the left side shows our cat eyes nodes with the sensing area in the range of 167 feet (500 meters) and the right side shows our map *US* 13.

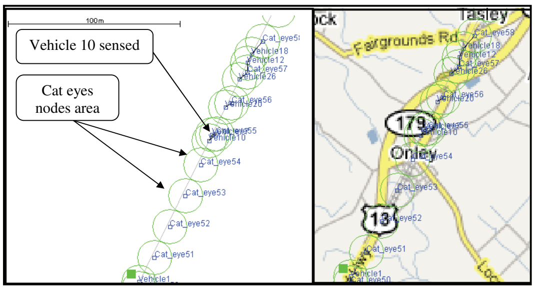

Fig. 5. Simulation- Left A - Right B

5.2. Evaluation

In evaluation, simulation data is analyzed to get the value of cluster size. our first scenario, we calculate the cluster size (number of nodes required) in order to detect all vehicles moving with maximum speed of 55mile/hr. We expect that the higher the density of the vehicles on the highway, the smaller the size of the cluster, the more able to detect the vehicles on the Highway. At the same time , we cannot increase the cluster size more than 8 nodes as it will disconnect clusters and prevent cluster communication.

5.2.1. Scenario A: No Sleeping Mode

As shown in figure 6,we compare three cases (Low density highways, high density highways with same speed vehicles and the high density highways with different speed vehicles which we call it HDensity2 in figure 6. The cluster size increases faster in the case of Low density highway. On the other hand, it takes more time in high flow traffic highway and in the case of different speed vehicles.

5.2.2. Scenario B: With Sleeping Mode

In the second scenario, we assume that the traffic is at night mode highway traffic or constructions on the highway. Our nodes will sleep for couple of mins depending on the number of vehicles passing. As shown in figure 7 , it takes more time to increase the cluster size, this happens when nodes are sleeping no increasing is allowed. Also, the low density highways are more faster to

Table 1. Simulation Settings

Parameters	Values
Number of Lanes	Two
Highway Length	≈11 miles
No. of groups on the highway	Two
Buffer size for two groups	10
Group I Max Speed	zero mile/hr
Model Movement Group I	Stationary Movement
Group II Max Speed	100km/hr=55 mile/hr
Model Movement Group II	Map based Movement
Simulation Time	30 min= 1800 sec
GUI Map	US-13 11.2 mi
Model Movement	StationaryMovement

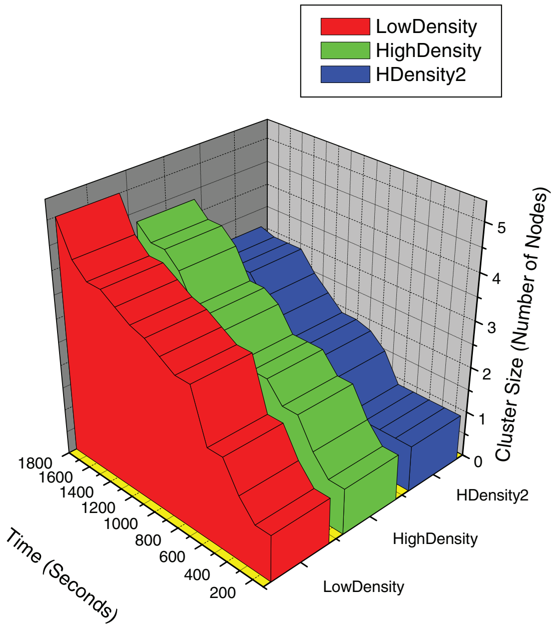

Fig. 6. Simulation- results - Awake Mode

increase in cluster size than the high density highways where the flow of traffic is very high.

In summary, our results show that cluster size changes depending on the traffic flow. The higher the traffic flow, the less cluster size changing can happen. In awake mode, where sleeping is not allowed, cluster size is increasing faster than in sleeping mode.

6. Applications

Our frame work can help in implementing different types of applications in Vehicular Networks:

1. *Incident Detection:* Incident detection on highway is one of the important information required to help other drivers to take the right decision. Drivers would receive information about an incident before reaching it as to take another route or stop for a rest or even avoid any sudden accidents. Our nodes can help in forwarding these information not only forward but also backward to other vehicles coming.
2. *Real-Time Weather Notification system:* Our system is a perfect solution for real-time weather notification. Drivers need a reliable and accurate information on weather and road conditions. current systems such as RWIS -Road Weather Information system- uses environmental sensor stations to collect data, then this data is sent to Data Ingest System (MADIS) to provide information to users - not necessary drivers [14]. Still drivers would like to receive notifications of different road weather information such as Fog,ice, black ice , heavy rain , snow and tornados. By adding extra sensors , our system can detect different types of weather and notify drivers.
3. *Emergency Evacuation:* In case of emergency condition, our system can provide information to drivers about evacuation. Emergency mode in our system can allow the nodes to forward information without any speed or data collection.
4. *Data Collection for Department of Transportation Data Analysis:* Data collection can be used by Department of Transportation for periodically data analysis to take critical decision such as lane expansion and road maintenance.

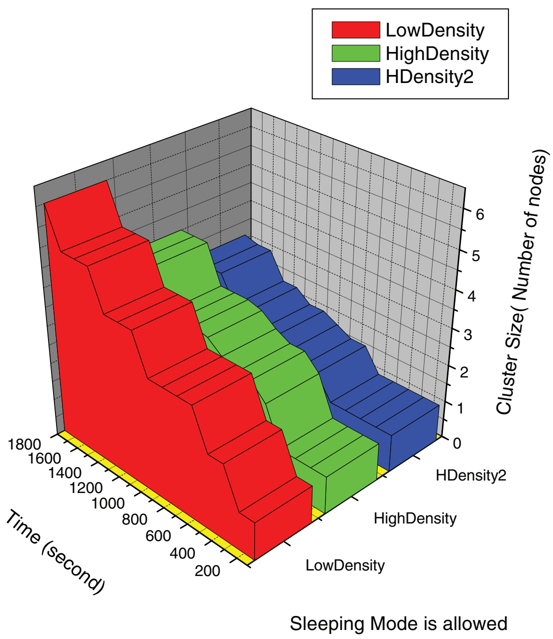

Fig. 7. Simulation- results - Sleeping Mode

7. Conclusion and Future Work

We have presented a new frame work for monitoring the highway and forwarding information using the deployed nodes on the highway. Our simulation calculated the cluster size (number of nodes with the same cluster). Our results show that the more vehicles with different speed on the highway, the less cluster size needed for communication and fast update. We also provide the update-status algorithm for the vehicles on the highway.These information can help in monitoring the highways. Also, we describe communication timing between nodes. Our future work, we would like to merge the vehicle-to-vehicle communication to our system which will allow forwarding information in case of dead clusters in the middle of the highway. Moreover, our plan is to develop a weather notification system on the highway by using our frame work and adding some other sensors that record more information about the weather around the nodes.

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