Real-Time Weather Notification System using Intelligent Vehicles and Smart Sensors

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***Abstract*—We introduce a real-time weather notification system in which drivers are notified with any bad weather conditions on the road including icy conditions or foggy conditions. Different type of bad weather requires different type of detection. We combine all cases by placing sensors uniformly to the road with an intelligent vehicles that communicate with the surrounding vehicles and the road itself. Our system depends on the spread sensors placed uniformly on the highway to monitor the road traffic. Cat eye's on the road which has been used for years as a reflectors to help drivers over night or at bad weather conditions can be more smart or intelligent by adding sensing capabilities. Intelligent vehicles can help in detecting some types of bad weather conditions and with the help of the sensors over the road using a combination of vehicle-to-vehicle communication and vehicle-to-infrastructure communication, we can reach a system that gives real-time notice for the drivers. Embedded processors are built inside the sensor over the road to allow the node to process these information.**

***Keywords*-Vehicular Networks,Smart Sensors,Meteorological Stations,Bayesian Model**

I. Introduction

In the United States, motor vehicle traffic crashes are the leading cause of death for all Americans betweens two and thirty four years of age [12]. In 2006, the National Highway Traffic Safety Administration reports that 42,642 people were killed in motor vehicle traffic crashes [5]. Among all these accidents , each year, approximately 7,000 highway deaths and 800,000 injuries are associated with about 1.2 million weather-related accidents.the estimated annual cost from these weather-related crashes(deaths, injures and property) amounts to nearly 42 billion [11]. To alert drivers with weather conditions including heavy rain,snow,sleet,fog,smoke,dust,ice and black ice can reduce the risks of accidents and improve the safety and efficiency of the roads.Vehicular Network research targets these problems. The main focus of researcher is to invent a new technology without expensive changes in the infrastructure to help notifying the drivers with bad weather conditions.

Drivers need a reliable and accurate information on weather and road conditions in a real-time method as to be able to take decisions such as speeding level. Several systems has been introduced. **Road Weather Information system (RWIS)** - RWIS is a combination of technologies that collects, transmit, models, and disseminates weather and road condition information[6]. The element of an RWIS that collects weather data is called the environmental sensor station (ESS). Road Weather Information System is a unique system consisting of several meteorological stations strategically located alongside the highway that allow the Department to make more informed decisions during winter storms. Specialized equipment and computer programs monitor air and pavement temperature to make forecasts regarding how the winter storms impact the highways. This gives the Department opportunities to utilize alternate de-icing chemicals, make optimal use of materials and staff, and practice anti-icing techniques developed through years of research. Meteorological Assimilation Data Ingest System(MADIS) is a framework for a national clearinghouse of RWIS data. Some State Departments of Transportation (DOTs) provide the information to be entered into the database, which can then be distributed to users of road weather information [6]. Finally, **Maintenance Decision support System (MDSS)**, a project that takes road weather data and information and merges them into a computerized winter road maintenance program that can help to guide maintenance manager in making better road treatment decisions [6]. Unfortunately most of these systems require some processing time and are not available for real time system. Information is stored then processed then sent to maintenance managers, these information are not available for drivers. Highways is in a great need for a Real-time notification system for weather conditions. Our proposed system introduces a cost effective for monitoring the weather conditions.

Our system uses both vehicle-to-vehicle (V2V) communication and vehicle-to-infrastructure (V2I) communication. We take advantage of the Electronic Stability Control system (ESC) which uses several sensors to determine what the driver wants (input). Other sensors indicate the actual state of the vehicle (response). The control algorithm compares driver input to vehicle response (25 times per second) and decides, when necessary, to apply brakes and/or reduce throttle by the amounts calculated through the state space

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(set of equations used to model the dynamics of vehicle) [2]. We add some wireless communication feature for the ESC system to communicate not only with the vehicle itself but also with surrounding vehicles. Also, we uses Cat eyes - which are built in the road as reflectors that can help drivers to see the road in the bad weather conditions or at night - in the Vehicular Ad-hoc Networks (VANET) technology. By adding sensing capabilities to each node of Cat's eye. An Ad-hoc Network can be created that won't suffer from any network disconnection problem [14].

As weather conditions deteriorate , sensors can collect information and process these information to leader (Section III for details) on the road that can notify drivers as early as possible with weather conditions. The rest of the paper is organized as follows. In Section II, we discuss the main idea and related work. Our proposed system model is discussed in details in Section III. Model analysis is done in Section IV. Our simulation comes in Section V. Finally, Section VI is our conclusion and future work.

II. Main Idea and Related Work

A. Main Idea

The cat's eyes are placed along the road on both directions. The sensors will be places inside each cat's eye. These sensors will form a network to disseminate the information about each vehicle to the other nodes of the network. The information about a vehicle (occurrence,location at a particular time and any sensors notification of an unstable road condition due to icy road conditions) will be forwarded to the other nodes(Section III defines the node) on the road.

B. Related Work

Abuelela et al[1] propose "NOTICE" a secure architecture for notification of traffic incidents.In NOTICE,sensor belts are placed in the surface of the road every mile or so. In spite of the efficient and secure system, NOTICE involve a high maintenance cost, just like inductive loop detectors. Also, Karpiriski et al [8] 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 that can offered. We describe detailed information about our system mode of operation, synchronization of nodes, how to detect weather conditions and scalability.

III. Proposed Model

Our goal is to monitor the road weather, then notify drivers of any hidden or unclear bad weather conditions. Our idea depends on the Cat eyes placed on the road that allows forwarding data between clusters (a cluster is number of cat eyes). We allow cluster-to-cluster communication to forward our data. Also, we use the sensors embedded in the tires in the Electronic Stability Control (ESC) system to notify road sensors with any unstable conditions in the vehicles along the road.

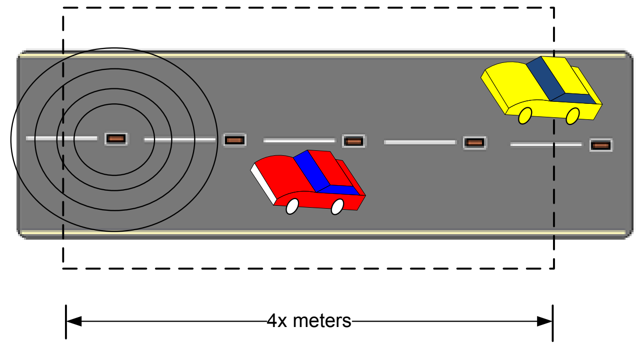

Figure 1. Cluster Definition

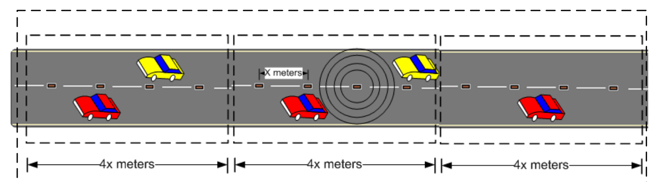

Figure 2. SubCluster Definition

A. Assumptions

We assume that each cat eyes in the road contains a sensor that measures (temperature,sound, metal detector and vibration). Also, each sensor contains an embedded processor that allows processing the data. We assume that the road can communicate with the vehicles and vice-versa. Moreover, a camera is used over the vehicles to capture the road and detect fog conditions.

B. Our System

We start with defining the concept of node over the road.Then,as shown in figure 1 and 2, we define the concept of Cluster,subCluster and SuperCluster:

1) Definition 1: Cat eyes sensor is refereed to as a node in our system. Each node has an embedded processor,small storage and a number that presents its location on the road.

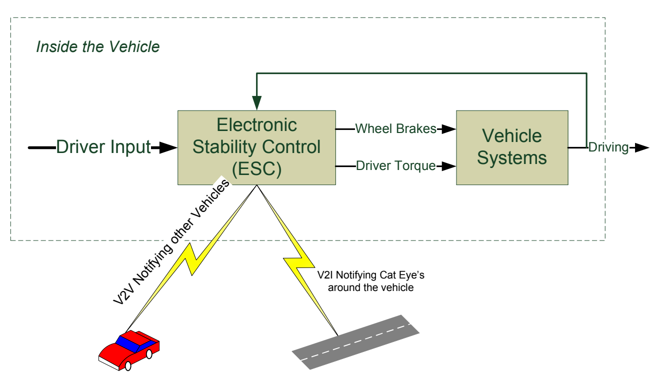

Figure 3. Electronic Stability Control Block Diagram

Syn #	Time	Temperature	Sound	Metal	Vibration	Mode	Sensor #	X,Y location	TTL	Unused

Figure 4. Packet Information

2) Definition 2: Let C_1 identifies a Cluster which is a rectangular area on the highway that covers the two lanes with length of $h * x$ where h is the number of nodes in the cluster and x is the distance between two consecutive road stubs (Cat's eyes). Given that the distance between cat's eyes is 24.3 meters(80 feet). A subCluster is a higher level concept that contains three consecutive clusters. Finally, a SuperCluster is the highest clustering level which contains 10 consecutive sub-clusters. At the end of the SuperClusters leaders exists. Leaders are nodes that collect information and take the decision of notifying vehicles or forward to next SuperCluster or just drop the information.

3) Definition 3: In figure 3, we add to the Electronic Stability Control (ESC) block diagram the wireless notification system that communicate not only with the vehicle itself but also with both surrounded vehicles using the vehicle-to-vehicle communication and the infrastructure nodes(our Cat eye's) using the vehicle-to-infrastructure communication. The driver input consists of the (steering angle,accelerator position,brake pressure)[3].

4) Packet Information: In figure 4, we show our packet information that used in our system which contains the Synchronization number which is used to Synchronize the nodes(Cat eye's) in one cluster, Time of packet sent,Temperature recorded in that location,medal detection existence, vibration value, sensor number, (in case of a vehicle: a random number generated is used as to keep the privacy of the vehicle (Vxxx)),a Time to live(TTL) value and finally extra space for any additional needed information.

C. Bayesian Network Model:

Bayesian Network are known to be used for calculating new beliefs when new information (evidence) is available[9]. The basic task of the inference system is to compute the posterior probability upon arrival of some evidences. In our case, new evidences would be -in the case of icy road condition- nodes temperature value and Electronic Stability Control Box signal. This is called belief updating or probabilistic inference. We consider the effect of new evidence on the probability of having a Weather Warning condition. Assume that we know from our data that the probability (our belief) of having a weather warning on a given section of the highway is p. For example, in icy conditions, if we noticed that there are some evidences about many ESC signals and low temperatures that are correlated in time and location (we can detect this from our packets information), then we may need to update our beliefs about having a weather warning that may exist and caused these many correlated ESC signals and low temperature. We consider a Bayesian network weather warning. We will ignore the case of **FREEZING FOG** which is the rare case of both fog and ice happen in the same time. Cloud droplets and liquid precipitation can remain liquid even when the air temperature surrounding the suspended or falling liquid is below freezing. This occurs because the liquid needs a surface to freeze upon. The liquid droplets will freeze without a nuclei surface if the temperature drops low enough. As a general rule, liquid cloud or precipitation drops between freezing and -10 C (14 F) will remain liquid. When the temperature drops to below -40 C, all liquid droplets will solidify. Droplets that are liquid and are below freezing are referred to as supercooled droplets[7].

Let $Pr[WW]$ be the probability of Weather warning condition. Let $Pr[F]$ and $Pr[I]$ be the probability of foggy condition and icy condition respectively. Since, we ignore the case of Freezing fog then, $Pr[F]$ and $Pr[I]$ are independent.Then , we have

$$\begin{aligned} Pr[WW] &= Pr[F \cup I] \\ &= Pr[F] + Pr[I] - Pr[F \cap I] \\ &= Pr[F] + Pr[I] \end{aligned}$$
$$where Pr[F \cap I] = 0$$

D. Detecting different weather conditions:

We have two main cases of weather conditions that results in an accident with a high probability, the foggy conditions and the icy roads. We will discuss the two cases and how to notify drivers with warning messages using our system.

1) Foggy Conditions: Fog is a visible aggregate of minute water droplets suspended in the atmosphere at or near the surface of the earth. When air is almost saturated with water vapor, this means that the relative humidity is close to 100%, and that fog can form in the presence of a sufficient number of condensation nuclei, which can be smoke or dust particles[4]. There are four types of classifications for fog. Thermal imaging camera can detect the existence of fog. In other research labs[10] ,they used camera to detect fog and classified it to three levels of thickening depending on the visibility (Heavy,Moderate and Light). Using the same technique, we would be able to detect fog and confirm this information using the Bayesian Model discussed above. We add a thermal camera to some vehicles on the road. When a case of low visibility occurs there is a chance that there is fog condition.

Let Pr[F] be a priori probability (or belief) an foggy condition at a given position on the road. When cameras above cars report a number of low visibility. evidences C's ,correlated in both time and position. we update our belief by using Bayesian mechanism.We computer the posteriori probability of a fog condition F at the given location as:

$$Bel(F) = \frac{Pr[F].Pr[C|F]}{Pr[C]} = \alpha Pr[F].Pr[C|F]$$

Where $Pr[C|I]$ is the likelihood . C represents any evidence such as Camera detection and α is computed by the law of total probability as

$$\alpha = \frac{1}{Pr[F].Pr[C|F] + Pr[\overline{F}].Pr[C|\overline{F}]}$$

Figure 5 shows a vehicle detecting a fog condition using the thermal camera.

2) Icy Conditions: In icy condition we depend on two factors the Electronic Stability Control (ESC) to detect instability situations and temperature measured from the sensors in the nodes over the road. Figure 6 shows vehicle notifying a icy condition. Using the same technique above, we would be able to detect icy condition and confirm this information using the Bayesian Model discussed.

Let Pr[I] be a priori probability (or belief) an icy condition at a given position on the road. When Electronic Stability Control box in the cars report a number of instability conditions. evidences E's ,correlated in both time and position. we update our belief by using Bayesian mechanism.We computer the posteriori probability of an icy condition I at the given location as:

$$Bel(I) = \frac{Pr[I].Pr[E|I]}{Pr[E]} = \beta Pr[I].Pr[E|I]$$

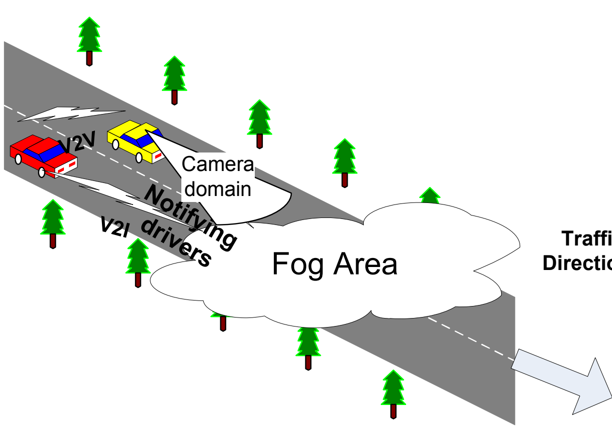

Figure 5. Vehicle suffering from Fog on the highway notifies the other vehicles and the infrastructure nodes

Where $Pr[E|I]$ is the likelihood . E represents any evidence such as temperature record or ESC signal and β is computed by the law of total probability as

$$\beta = \frac{1}{Pr[I].Pr[E|I] + Pr[\overline{I}].Pr[E|\overline{I}]}$$

Where $Pr[E|I]$ is the probability of temperature is being recorded low or the probability of the ESC signals given that there is icy conditio.Both depend on the sensitivity of the sensors in the Electronics Stability Control box and the sensor in the nodes placed over the road.

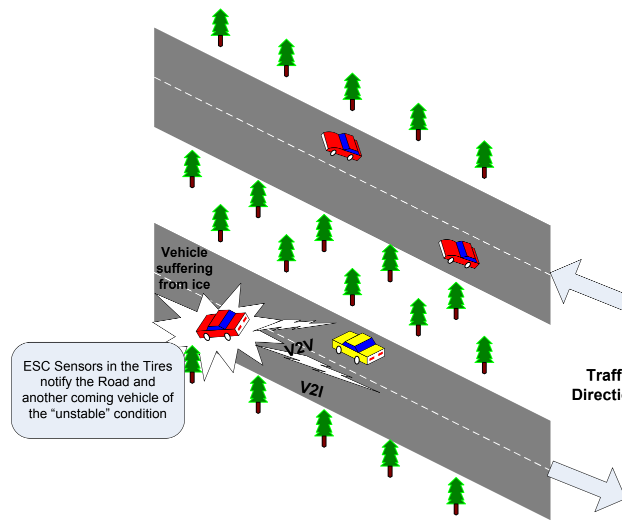

Figure 6. Vehicle suffering from Ice on the highway notifies the other vehicles and the infrastructure nodes

IV. Model Analysis

First, we discuss the infra-structure nodes and how it communicate with each other.Second, we give an algorithm to detect speed on highway. Then, we describe the analytical analysis for calculating the optimal cluster size on the road.

A. Clustering synchronization and Clustering Communications

In a cluster, every time T minutes, synchronization between nodes is required. Assume we have four sensors,sensor S_1 sends a packet with a random number (Syn no.) to all other three sensors, S_2 waits for receiving this packet for time interval T, after T, it assumes that S_1 is dead and starts transmitting its own packet with a random Syn to the other two sensors. If S_2 receives the packet from S_1 , it add its sensor number and forward it to sensor S_3 and S_4. Sensor S_3 will do the same, wait for amount of time 2T, nothing received from S_1 and S_2, it assumes that they are died and starts its transmission. If it receives the packet, then it forwards the Syn no with its sensor number to sensor S_4.

On sub-Cluster level, assume we have a sub-cluster of three clusters C_1,C_2 and C_3. Information will be forward from C_1 to C_2 with different syn no. and the recorded speed for each vector. Such information should be forward to the next cluster without any modifications. Leaders in each super-cluster decide whether the information should be forward further or notifications should be sent to drivers or just drop the packets as shown later in algorithm 1.

B. Speed Calculation

In order to calculate the average speed in a subCluster area, information is transferred between clusters to reach leaders. Leaders collect Vectors of data each contains time, temperature, syn, sensor number, and recorded values from different sensors. Assume a vehicle approaches sensor S_1, values of sound, vibration and metal detection are recorded at time t_1, these values are compared with values from the same cluster (same Syn number), to calculate speed. When the values are close and the difference doesn't exceed a threshold, speed can easily be calculated using the difference between time and distance between the two sensors.

Algorithm 1 Matching Vehicles And Speed Calculation

procedure MATCHVS-AND-SPEEDCAL($V_1(t_1,\upsilon_1\ ,\mu_1, \rho_1, mode_1\ ,Syn_1)$, $V_2(t_2,\upsilon_2\ ,\mu_2, \rho_2, mode_2\ ,Syn_2)$)
    define threshold value,T_y,υ_y,μ_y ,ρ_y;
    while $!Sleep$ **do** ▷ Loop1
        if Syn_1=Syn_2 **then**
            while $t_2 > t_1$ **do** ▷ Loop2
                if $|t_2 - t_1| < T_y$ **then**
                    if $|\upsilon_2 - \upsilon_1| < \upsilon_y$ and $|\mu_2 - \mu_1| < \mu_y$ and $|\rho_2 - \rho_1| < \rho_y$ **then**
                        Speed= $\delta/(t_2 - t_1)$;
                        Store Speed with vehicle data vector
                    end if
                end if
            end while
        end if
    end while
end procedure

In algorithm 1, the sensors keep testing -using the embedded processors- for matching speed. When two records are matched by syn numbers and time of recorded information is within a given threshold T_y and in the case of two records within a given threshold for sound υ_y, vibration μ_y and metal detection ρ_y values. Sensors will calculate the speed for each vehicle and forward record to other clusters.

C. Cluster Size (number of nodes per cluster)

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

- Rule 1: The range of the cluster should allow the sensor to communicate within same cluster even if some of the sensors are dead.
- Rule 2: The higher number of nodes in each cluster increases the probability that the vehicle is recorded in the cluster.
- Rule 3: The distance between nodes is fixed on highways.

It is clear from the above rules that the variable parameters are rule 1 and 2. From rule 3, assume that x is the fixed distance given on highway between Cat's eye (nodes). Also, assume that z is a random variable that donates the range of transmission of the nodes, then y that denotes the cluster size is calculated from $y \leq z + 2.\frac{x}{2}$.From rule 2, our model requires $max(y)$. Then:

- Rule 1: $y \leq z + x$
- Rule 2: max(y)
- Rule 3: Number of nodes = $\lfloor \frac{y}{x} \rfloor - 1$

Given that z the range of transmission is 300 feet and x is equal to 80 feet [**?**], [13]. Then, the maximum number of nodes in a cluster is equal to four and at least two nodes are required two calculate speed of vehicles. Then, number of nodes in a cluster range from 2,3 or 4 nodes. From rule 2, then our model will use four nodes in a cluster.

V. SIMULATION

In the simulation, we calculate the optimal value for the cluster size. On a high density highway; senors are always in the awake mode, 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. Our model compares the ratio of messages dropped over all messages that passed in a cluster with different cluster sizes. Cluster size more than 4 nodes will not allow cluster to cluster communication as the range of transmission of our nodes is less than 300 feet [13].The simulation parameters and values are listed in Table I.

A. Evaluation

In evaluation, simulation data is analyzed to get the optimal value of cluster size. , we calculate the cluster size (number of nodes required) in order to detect all vehicles moving with maximum speed of 55mile/hr, simulation results are taken and analyzed assume the three different cases (size of 2,3 and 4). We expect that the larger 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 4 nodes as it will disconnect clusters and prevent cluster communication. As shown in figure 7, Cluster size (where 4 cat's eyes are in one cluster) is better in detecting all vehicles

Table I
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	Head northeast on US-13 11.2 mi
Model Movement	StationaryMovement

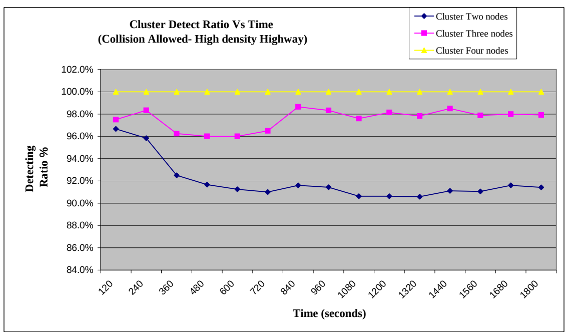

Figure 7. Simulation- results - Awake Mode

moving with maximum speed of 55mile/hr,while in the two and three nodes per cluster suffers from some loss.

VI. CONCLUSION AND FUTURE WORK

We have presented a new system work for monitoring the bad weather conditions on highways and forwarding information using the spread nodes on the highway and the surrounding vehicles. Our system will benefit all vehicles coming on the highway even the one that does not have our system installed. We also provide an algorithm when to notify drivers on the road. In summary, our results show that four nodes cluster is sufficient to detect vehicles over the highway and calculate there average speed. Also, our system will be working in case of dead nodes, in case of one or two nodes is dead, cluster can still calculate speed and forward information to other clusters. In case of three nodes died, cluster will not be able to calculate speed or information but still can forward information. In case of all four nodes are dead, cluster to cluster communication is still valid as the last node in the pervious cluster can communicate with the first node in the next cluster (in communication range). Finally, the case where two consecutive clusters are dead , this will result in a gap in our system which is expected not to happen unless on purpose maintenance.

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