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16. Abstract

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Risk Assessment, Identification, and Notification (RAIN) System: A Novel Approach for Traffic Management

FINAL REPORT

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Abstract

The Center for Defense Integrated Data (CDID) at Jackson State University (JSU) conducted research on the development of a Risk Assessment, Identification, and Notification (RAIN) System that could identify high-risk transportation areas and disseminate notification messages to vehicles approaching those zones. This report discusses work on broadcast protocols; outlines the methodology for a Risk Notification Message Dissemination Protocol; and presents the simulation results with respect to different conditions.

Primary research focused on the design and development of an energy-efficient Risk Notification Message Dissemination Protocol (RNMDP) for vehicular ad hoc networks (VANETs). RNMDP propagates Risk Notification Messages (RNMs) from a location of origin to vehicles approaching a Risk Zone. The performance of RNMDP was compared with that of the commonly used flooding strategy through extensive simulations conducted for highway networks with different numbers of lanes and lane density. Simulation results indicate that with a slightly larger delay, RNMDP can achieve the same message delivery ratio attained by flooding, but at a relatively much lower energy loss compared to flooding. RNMDP has been designed to minimize the energy lost in the propagation of the RNMs, but at the same time incur the least possible delay in delivering the messages.

As part of this project, graduate students at CDID also initiated supplemental research focusing on the development of a small, lightweight, easily deployable wireless traffic density counter to capture data and to aid in the management of traffic flow. The measurement of traffic volume is a fundamental function of highway planning and management, and traffic volume counts provide one of the most common measures of traffic engineering analysis. This novel network of wireless sensors may offer greater flexibility and lower maintenance than prior technologies.

1.0 Introduction

The current state of the nation's transportation infrastructure and the threat from natural or manmade disasters, demands a comprehensive approach for metropolitan safety, security, management and mobility. Developing an intelligent data acquisition and dissemination system can provide a means for reporting on the critical network necessary for the daily movement of goods and persons throughout the country. Vehicular Adhoc Networks (VANETs) represent one of the most promising areas in intelligent transportation systems, having applications in road monitoring, traffic management, safety broadcasting, and congestion notification.

These networks are valuable components of Mobile Ad hoc Networks (MANETs). MANETS are dynamic distributed systems of mobile nodes that enable vehicles to receive and relay messages through wireless networks. These important announcements can provide drivers with timely and essential information regarding traffic volume, collision warnings, congestion, road flooding, bridge closures, and evacuation notifications that can help drivers avoid high risk areas. In addition, these ad hoc sensor networks offer certain capabilities and enhancements that can increase alertness to potential risks on critical transportation corridors.

A primary objective of VANET communications is to assist with safer driving and to provide timely information to drivers and other concerned authorities [1]. To accomplish this objective, it is imperative to develop fast and reliable broadcast message dissemination protocols to propagate warning messages (accidents, unexpected fog banks, dangerous road surface conditions, etc.) to upcoming vehicles on the road. The alert messages should be delivered to the largest number of upstream vehicles in the shortest amount of time. Flooding is one of the most commonly used approaches in ad hoc networks to disseminate a message from one node to every other node in the network. Flooding, however, leads to a significant amount of energy and bandwidth consumption as each node in the network is required to broadcast the message in its neighborhood [2].

Communication in VANETs can be of two types: vehicle-to-vehicle communication and roadside-to-vehicle communication. VANET communication is normally accomplished through special electronic devices placed inside each vehicle so that an ad hoc network of the vehicles is formed on the road. A vehicle equipped with a VANET device should be able to receive and relay messages to other VANET-device equipped vehicles within its specified radius.

A primary difference between a MANET and a VANET is in the mobility of the nodes involved. The mobility of the vehicles in VANETs is mostly constrained to follow a pattern (car following model [3], in which cars follow one after another in a streamlined fashion), and is different from the random mobility of the nodes as seen in MANETs. Nevertheless, there are several commonalities between MANETs and VANETs, including energy consumption. Like MANETs, VANET devices are also battery powered; and it is of utmost importance that communication protocols developed for VANETs be energy sensitive, consuming as little energy as possible.

2.0 Objectives

The objective of this research is to design and develop a Risk Notification Message Dissemination Protocol (RNMDP) for vehicular ad hoc networks that can be used to receive and relay messages through wireless networks, thereby improving safety and communication among drivers in high risk areas. Researchers focused on the development of an energy-efficient integrated protocol to propagate these notification messages.

Risk Notification Message Dissemination Protocol works by propagating notification messages from a Risk Zone to vehicles approaching these hazardous areas, called Target Zones. Each vehicle on the road is assumed to be capable of determining its current location in the network (using Global Positioning System (GPS) location services [4]). All vehicles are assumed to operate in a fixed transmission range. The RNM is broadcast by an initiating device in the Risk Zone in its neighborhood defined by the transmission range. Every node receiving the RNM waits for a time called the Rebroadcast-Wait-Time before rebroadcasting the message. The value of the Rebroadcast-Wait-Time for a node depends on the distance of the node to the sender of the RNM (the ratio of the distance between these two nodes) and the direction of movement of the vehicle. During the Rebroadcast-Wait-Time, if a node hears the same RNM again in its neighborhood, the node does not rebroadcast the message. If a node does not hear the RNM during the Rebroadcast-Wait-Time, the node rebroadcasts the message in its neighborhood defined by the transmission range. A RNM is considered to have been delivered to all the vehicles on the road, if the message reaches the Target Zone.

RNMDP incurs the least number of intermediate retransmitting nodes to rebroadcast the RNM. Hence, it consumes the least amount of energy. The team used flooding as the benchmark to compare and evaluate the performance of RNMDP under different conditions of lane density and number of lanes. Performance simulation studies illustrate that the Rebroadcast-Wait-Time does not significantly increase the end-to-end delay for the messages delivered. RNMDP performs very well especially in high lane density networks incurring the least possible energy consumption with a delay very close to that incurred with flooding.

3.0 RNMDP Methodology

The Smart Broadcast (SB) protocol divides the rectangular forward area (called the area unit, AU) covered by the transmission range of a node into several sectors, controlled by a parameter identified as N_S [5]. Each sector covers a fraction $1/N_S$ of an AU. The notification messages to be broadcast include the location information of the current transmitter of the message. Each node receiving the notification message chooses a rebroadcast-latency depending on the sector in which the node is located. Nodes lying in a sector far away from the sender will get the priority to rebroadcast the message. Some of the potential problems with the SB protocol are that all

Figure 3.1:Dr. Gordon Skelton and Graduate Student, Venu Peddireddy, discuss research methodology at the Center for Defense Integrated Data.

nodes lying with in the far-away sector will contend for channel access to rebroadcast the message and this can lead to unnecessary message collisions. The value of the parameter N_S has to be dynamically chosen depending on the lane density and the number of lanes. Also, the SB protocol only allows nodes that are approaching the source of the broadcast to propagate the message downstream. This can lead to poor connectivity in low density networks. RNMDP does not have to deal with channel contention issues as only one node gets the highest priority to rebroadcast the message. RNMDP effectively deals with low lane density scenarios by allowing nodes traveling in lanes in the direction away from the Risk Zone to rebroadcast a message, albeit with a higher Rebroadcast-Wait-Time.

In the Distributed Vehicular Broadcast (DV-CAST) protocol [6], each node is assumed to periodically exchange beacons in its neighborhood to determine the status of the neighborhood, which could be categorized as: well-connected, sparsely-connected or totally disconnected. A node handles the broadcast message received depending on the status of its neighborhood. To avoid redundant broadcasts in a well-connected neighborhood, a broadcast suppression mechanism is used during which a node listens to the neighborhood for the number of redundant broadcasts received before deciding whether to propagate or not. Periodic beacon exchange is a core-requirement of DV-CAST and this can lead to high bandwidth and energy consumption. The RNMDP protocol proposed in this paper is beaconless, i.e., does not require the periodic exchange of beacons in the neighborhood.

In the Backfire algorithm a node immediately rebroadcasts a message if it receives a message from a node that is separated from it by a distance greater than a threshold value of D_{max} [7]. A node, whose distance to the originator is below the threshold D_{max} value, waits for a time proportional to the distance to the originator. If a rebroadcast message is heard from some other node during this waiting time, the node decides to drop the message. The proper selection of D_{max} value, depending on the node transmission range and lane density, is very critical for the Backfire algorithm to function effectively. RNMDP does not employ any such critical parameters that have to be differently configured in different operating scenarios.

4.0 Assumptions

RNMDP will use one dedicated frequency channel in the Intelligent Transport Systems, ITS, band of 5.85 – 5.925 GHz [8] and the channel will be well separated from the frequency channels used for comfort applications. A vehicle will have to tune to the RNMDP channel to receive messages corresponding to this protocol. In the rollout phase (the time period during which the majority of the vehicles are not designed to be compatible with the ITS band), where only one frequency channel may be used for all vehicular communications, RNMDP messages will be given more priority over messages belonging to other non-emergency, comfort applications. RNMDP assumes that all the vehicles using the protocol are GPS-enabled. Using Global Positioning System (GPS) [4], a vehicle can learn its own position on the road. For simplicity, in the description of the protocol in this paper, we assume a highway having two lanes in opposite directions. RNMDP will also work for highways with multiple lanes in same or opposite directions. The mobility model for the vehicles is the commonly used car-following model [1], according to which the speed of a vehicle is dependent on the speed of the vehicle ahead of it and the distance between the two vehicles.

5.0 RNMDP Protocol Description

Let (X_{min}, Y_{min}, X_{max}, Y_{max}) be the boundaries of the area (hereafter called the "Risk Zone") about which the vehicles traveling towards it need to be aware of. The Risk Notification Message (RNM) is originated to spread any risk, safety threat or warning information for this area. The message could be initiated by a police vehicle on the road or a sink node gathering information from the sensors located near the Risk Zone. Each time a RNM is initiated near the Risk Zone, its contents could be different depending upon the up-to-date status of the Risk Zone. In Figure 5.1, node A is the initial sender of the RNM. Note that the words "node" and "vehicle" are used interchangeably, to mean the same.

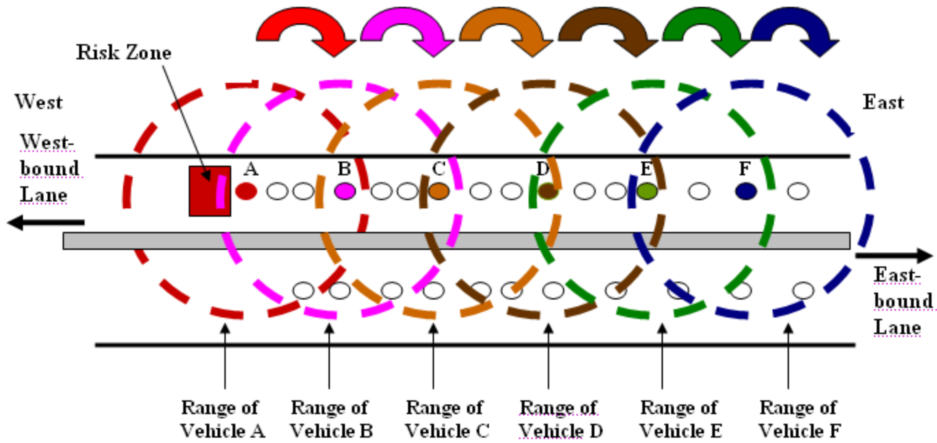

Figure 5.1: Propagation of the Risk Notification Message (RNM) away from the Risk Zone

The RNM (Figure 5.1) has 69 bytes of control overhead and the data portion of the message (the actual risk notification) is of size at most 512 bytes, typical value for medium-sized messages in ad hoc networks. The RNM is first broadcast around the neighborhood of the initiator node. A distinct value for the *Message ID* field would be used to indicate that the message is a RNM and is different from messages belonging to other applications. The RNMs are periodically broadcast until the Risk Zone is danger-free and the vehicles could pass through it without any harm. The time at which the first RNM is initiated due to the current risk at the Risk Zone is included in all the RNMs sent from that zone. The coordinates of the Risk Zone and the time of origin of the first RNM are together used to distinguish between RNMs originating at different locations at different time instants. RNMs from a particular Risk Zone with the same timestamp of origin are distinguished from one another using monotonically increasing sequence numbers.

Message ID	Sequence Number	[X_{min}, Y_{min}, X_{max}, Y_{max}] Risk Location	[X_S, Y_S] Sender Location	Sender Node ID	Time First Message Initiated	Maximum Number of Hops	Direction	Risk Notification Message
4 bits	4 bytes	32 bytes	16 bytes	4 bytes	8 bytes	4 bytes	4 bits	Maximum of 512 bytes

Figure 5.2: Structure of the Risk Notification Message (RNM) used by RNMDP

6.0 Direction of Propagation

The direction the RNM should propagate is indicated using the 4-bit "Directions" field by using unique identifiers for each of the eight possible directions (North, North-east, East, South-east, South, South-west, West and North-west). If the message needs to be propagated in all directions, then all the 4 bits of the Directions field are set to 1. As the risk information should be notified to the vehicles that approach the Risk Zone, preference to rebroadcast would be given to the vehicles traveling towards the Risk Zone.

7.0 Maximum Number of Hops for Propagation

The initiator sets the maximum number of hops a RNM could be broadcast in the "Maximum Number of Hops" field. The value of this field, as set by the initiator, is greater than zero. Each node receiving a RNM with a particular sequence number for the first time, decrements the *Maximum Number of Hops* field in the message by 1, before deciding to broadcast the message further. If the value of the *Maximum Number of Hops* field is equal to zero, then the node discards the RNM. Otherwise, i.e., if the value of the field is still greater than zero, the node waits for a "Rebroadcast-Wait-Time" before deciding whether to further rebroadcast the message or not. When a node decides to rebroadcast the RNM after its Rebroadcast-Wait-Time expires, it updates the values of the Sender Location (X_S, Y_S) and *Sender Node ID* fields in the message using values that indicates itself. In Figure 5.1, the sequence of nodes that rebroadcasts the RNM would be A, B, C, D, E and F, one node per hop count value.

8.0 Rebroadcast Wait Time

Every node does not forward the message, as this would cause generation of redundant messages and message collisions, which may trigger the familiar broadcast storm problem [3]. Let D denote the "Maximum Rebroadcast-Wait-Time", R be the distance between a node and the node from which it received the RNM and R_{max} be the maximum transmission range of the nodes (which for simplicity, is the same for all nodes) in the network.

For nodes traveling towards the Risk Zone, the Rebroadcast-Wait-Time = $\{D*(1-R/R_{max})/2\}$. During this Rebroadcast-Wait-time, if the node receives a RNM with a *Maximum Number of Hops* value that it has already seen, then the node does not rebroadcast the message. If no such RNM is received within the Rebroadcast-Wait-time, the node decides to rebroadcast the message in its neighborhood. The above equation illustrates that preference to rebroadcast is given to the neighbor node that is the farthest from the sender of the RNM. In Figure 5.1, node B would rebroadcast the RNM received from node A.

In order to make RNMDP robust and improve the chances of disseminating the RNM to the nodes approaching the Risk Zone, researchers also considered broadcasting through nodes traveling in lanes in the direction away from the Risk Zone. These nodes are made to wait for Rebroadcast-Wait-Time = $[(D/2) + \{D*(1-R/R_{max})/2\}]$ before propagation. Note that first preference is still given for rebroadcast by nodes traveling towards the Risk zone. Only if there are no such nodes to rebroadcast, especially in sparsely dense networks, nodes traveling away from the Risk zone are considered for rebroadcast. Among such nodes, the node traveling farthest away from the sender of the RNM is preferred.

9.0 Simulations

The research team implemented RNMDP in a discrete-event simulator, developed in Java, and compared the performance of RNMDP with that of the conventionally used flooding algorithm to disseminate messages from one node to every other node in an ad hoc network. Analysts conducted simulations with networks depicting highways of dimensions 5m x 8000m (unidirectional with only one lane) and 10m x 8000m (bidirectional with two lanes, in opposite directions). The width of each lane was 5m for both the highways. Note that 'm' as a unit notation corresponds to meters and not miles. For each highway, the Risk Zone was assumed to be located at (0, 0) and the location up to which the risk notification message has to propagate (i.e., the Target Zone) is assumed to be at (5, 5000). Accordingly, the minimum distance between two vehicles (referred as the safe distance) in a lane was 92 meters, coinciding with an Interstate vehicular speed of 65-70 miles per hour.

Simulations were conducted for highways with three different lane density values. Highways with 30, 45 and 60 nodes per lane were referred to as low, medium and high lane density networks respectively. Each vehicle moves with a speed uniformly distributed between 65 to 70 miles per hour. The mobility model used was the widely used car-following model [1]. The MAC layer model followed was the IEEE 802.11 model [9]. Each node was location-aware and could identify its location in the network at any point of time. The energy consumed due to broadcast transmission of a message within the neighborhood was $1.1182+7.2*10^{-11}*R^4$ where R is the transmission range of a node. The energy consumed to receive a message was 1W [10]. The team only considered the energy losses due to transmission and reception.

For both the highways, the number of RNMs sent from the Risk Zone to the Target Zone was 4000. The messages were sent at the rate of 1 message per second, periodically one after another. The message size was 512 bytes. The channel bandwidth was assumed to be 2 Mbps. Simulations were conducted for different transmission range per node values: 250m to 1000m, in increments of 50m. For a given simulation, the transmission range of all the nodes was fixed and the same. Each node had a queue of size 200 and the queue worked in First-In-Out-First fashion. The team assumed that the propagation of the RNM was the only event happening in the network and that there was no other data exchange event taking place. The value of the Maximum-Rebroadcast-Wait-Time was 1 sec. Analysts assumed that there was a transmitting node at the Risk Zone and a receiving node at the Target Zone. The node in the Target Zone had to receive the RNM in order to conclude that the message propagated the entire region of the highway lane starting from the Risk Zone to the Target Zone and that every other node in this region also received the message. For a given simulation condition, the performance metrics values plotted in Figures 11.1 through 11.6 were an average of the values collected by running simulations with 5 samples of node mobility profile.

10.0 Message Delivery Ratio

The message delivery ratio, a measure of network connectivity, is the ratio of the number of messages received at the Target Zone to the number of messages transmitted from the Risk Zone. For a given simulation condition, researchers obtained identical message delivery ratios for both flooding and RNMDP. For the highways with one lane (refer Figure 11.1.1) and two lanes (refer Figure 11.2.1), the message delivery ratio reached unity only when the lane density was moderate and high. For a given lane density, the minimum transmission range per node values at which the message delivery ratio reached unity was almost the same for both the highways. Nevertheless, for low lane density networks, and for highways with two lanes, the message delivery ratio was more than 0.9 for transmission range per node values starting from 750m. Thus, adding a second lane was relatively more effective for networks with low lane density.

11.0 Energy Lost per Message Delivered

This metric is the sum of the transmission energy and receiving energy consumed at every node in the network during the broadcast of the RNM from the Risk Zone to the Target Zone. In the case of RNMDP (Figures 11.1.2 and 11.2.2), to achieve 100% or the maximum possible message delivery, the number of nodes required to retransmit decreased as the transmission range per node increased. But, the larger the transmission range, the more the energy consumed to guarantee 100% or the maximum possible message delivery. Hence, for a given highway and lane density, it would be wise to operate at a transmission range (called the critical transmission range) such that the network incurs the lowest energy consumption, but still achieves 100% or the maximum possible message delivery ratio. For both high and moderate lane density networks, as the number of lanes increased from one to two, the critical transmission range decreased by 12%. However, at these critical transmission range values, the energy lost per message delivered in highway with two lanes was 5% and 70% more than the energy lost per message delivered in highway with one lane at moderate and high lane densities respectively. For low lane density networks, RNMDP could not achieve 100% message delivery even at the maximum transmission range of 1000m and at this range value, the energy lost per message delivered in highway with two lanes was only 8-10% more than the energy lost in highway with one lane.

For a given lane density, as the number of lanes increased from one to two, the energy lost per message delivered increased by a factor of 70-90% at transmission range per node values $\leq$ 400m and by a factor of 7-20% at transmission range per node values > 900m. As the transmission range per node increased, the decrease in the rate of increase of energy lost per message delivered was attributed to the reduction in the number of hops the message travels from the Risk Zone to the Target Zone. A similar observation can be made when lane density increased from low to moderate and to high, for highway with a given number of lanes. As the team increased the transmission range per node value from 250m to 1000m, the average hop count per path traversed by RNM decreases by approximately 75% to 80%. For a given transmission range per node and number of lanes, as lane density increased from low to high, the average hop count per path decreased by 10-15% due to the increase in the chances of selecting a node farthest away from the sender.

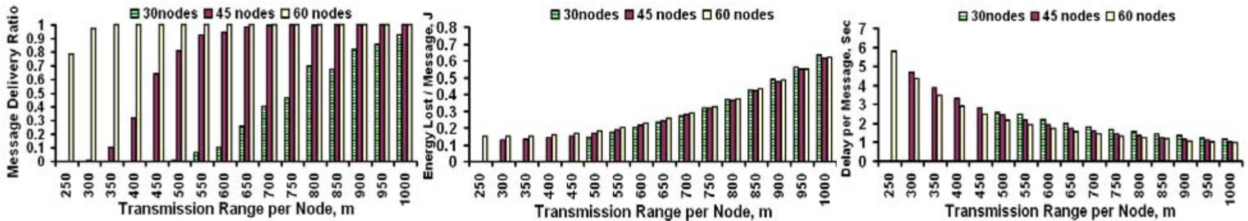

Figure 11.1.1: Message Delivery Ratio | **Figure 11.1.2: Energy Lost per Message** | **Figure 11.1.3: Delay per Message**

Figure 11.1: Performance of RNMDP (Highway with One Lane)

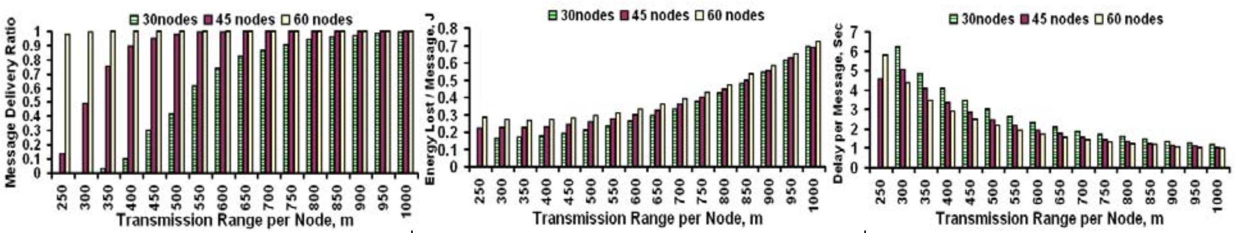

Figure 11.2.1: **Message Delivery Ratio** | **Figure 11.2.2: Energy Lost per Message** | **Figure 11.2.3: Delay per Message**

Figure 11.2 : **Performance of RNMDP (Highway with Two Lanes)**

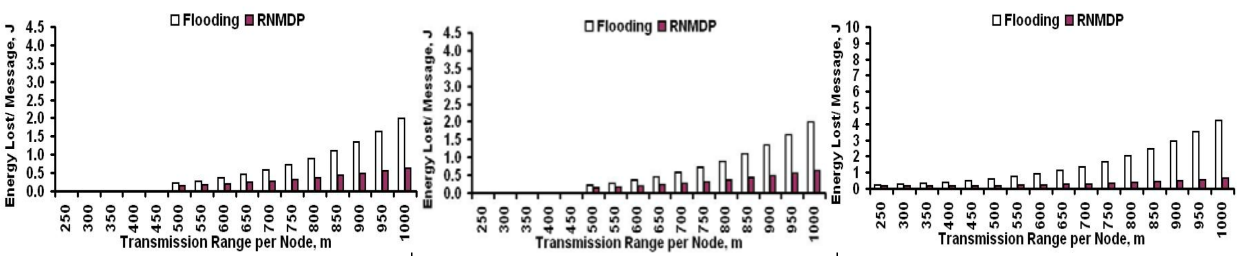

Figure 11.3.1: Low Lane Density | **Figure 11.3.2: Moderate Lane Density** | **Figure 11.3.3: High Lane Density**

Figure 11.3: RNMDP vs. Flooding: Energy Lost per Message Delivered (Highway with One Lane)

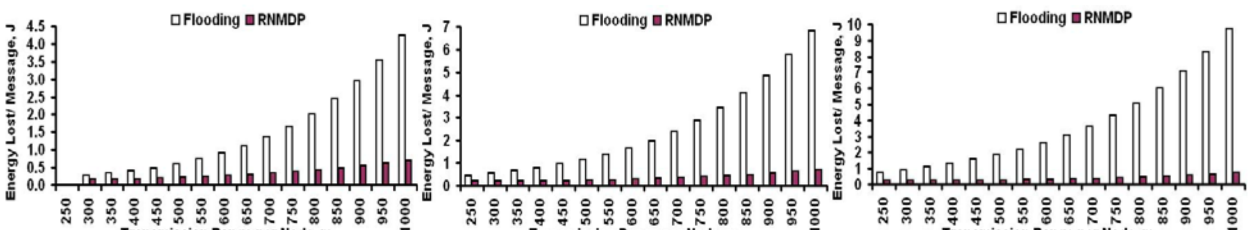

Figure 11.4.1: **Low Lane Density** | **Figure 11.4.2: Moderate Lane Density** | **Figure 11.4.3: High Lane Density**

Figure 11.4: RNMDP vs. Flooding: Energy Lost per Message Delivered (Highway with Two Lanes)

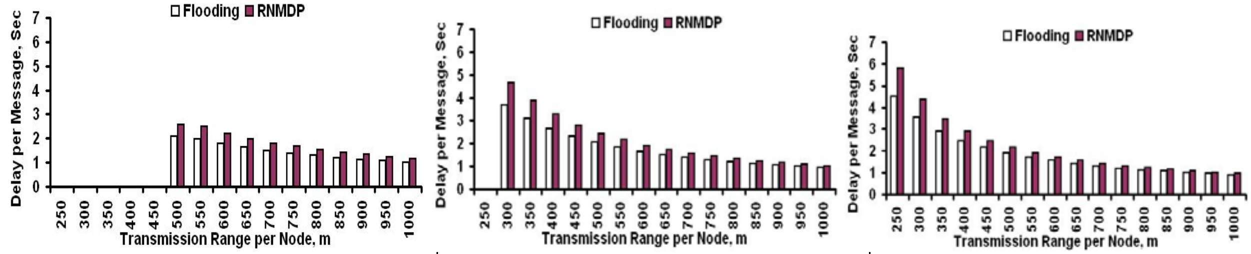

Figure 11.5.1: Low Lane Density | **Figure 11.5.2: Moderate Lane Density** | **Figure 11.5.3: High Lane Density**

Figure 11.5: RNMDP vs. Flooding: Delay per Message Delivered (Highway with One Lane)

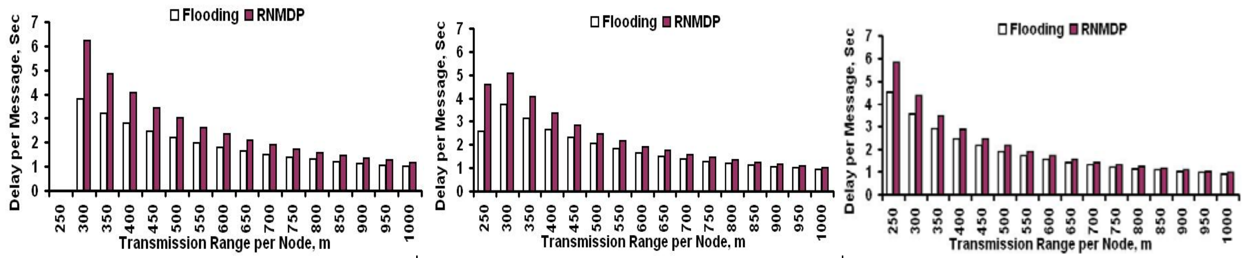

Figure 11.6.1: Low Lane Density | **Figure 11.6.2: Moderate Lane Density** | **Figure 11.6.3:High Lane Density**

Figure 11.6: RNMDP vs. Flooding: Delay per Message Delivered (Highway with Two Lanes)

12.0 RNMDP vs. Flooding

RNMDP incurs the lowest energy lost per message delivered for all the scenarios simulated (Figures 11.3 and 11.4). This is justified by the relative reduction in the number of nodes retransmitting the RNM compared to flooding. For a given lane density, as the transmission range per node is increased from 250m to 1000m, energy lost due to flooding increases significantly. Similarly, for a fixed transmission range per node, with increase in the lane density and/or the number of lanes, energy lost due to flooding increases significantly. With flooding, each node has to transmit the RNM exactly once, irrespective of the transmission range. For a given lane density, in both one lane and two lane scenarios, the magnitude of the difference of the energy lost due to RNMDP and flooding increases as we increase the transmission range per node. In the case of RNMDP, as the transmission range per node increases, the number of hops traversed by the RNM decreases significantly. Also, for a fixed number of lanes and transmission range per node, the hop count per path for RNMDP slightly decreases with increase in the lane density.

13.0 Delay per Message Delivered

This metric refers to the average of the end-to-end delays incurred by a RNM from the Risk Zone to the Target Zone. The end-to-end delay per message is the sum of the propagation and transmission delays at each hop and the channel access delay and queuing delay at each intermediate node that forwards the message.

In low lane density scenarios, for a given transmission range per node, as the number of lanes increased from one to two (Figures 11.1.3 and 11.2.3), the increase in the end-to-end delay is by a factor of 5-8% for transmission range per node ≤ 750m and is only by 2-3% for transmission range values above 750m. At the same time, the message delivery ratio increased by 40-60% when a second lane was added. The slightly larger delay for highways with two lanes compared to the highways with one lane can be attributed to the slightly larger Broadcast-Wait-Time suffered by the messages when transmitted by nodes that are far away from each other. For moderate lane density scenarios, even though the message delivery ratio increases significantly with the introduction of the second lane, there is no significant difference in the delay suffered by the messages. At high lane density scenarios, the message delivery ratio improved only marginally (by 20% for transmission range values below 300m), and the delay per message almost remained the same for both highway with one lane and highway with two lanes scenarios.

For a given highway and a fixed transmission range per node value, the delay per message decreased with an increase in lane density. This is due to the relatively lower hop count incurred by the RNM in networks of higher and moderate lane density. For a given highway and a fixed transmission range per node, the delay per message in high lane density networks was 70-83% in low lane density networks and 85-95% in moderate density networks. For a given lane density and highway, as the transmission range per node is increased, the end-to-end delay per message also decreases. But the decrease was at a faster rate as the transmission range increased to a moderate value of 500-600m. With further increase in the transmission range per node, the rate of decrease in the delay per packet was slower. This was due to the larger channel access delays and the larger queuing delays at the nodes in networks of larger neighborhood size.

In the case of flooding, the RNMs propagate through multiple paths from the Risk Zone to the Target Zone. For the purpose of measuring the end-to-end delay per message delivered, the research team considered only end-to-end delays incurred by the first RNM reaching the Target Zone. For a given lane density and transmission range per node, the end-to-end delay suffered by the first message reaching the Target Zone using the flooding approach was independent of the number of lanes in the highway. For a given highway and transmission range per node, as the lane density is increased from low to moderate and from low to high, the delay per message delivered for flooding decreases by 8% and 10-14% respectively. Similar to RNMDP, in the case of flooding, for a given lane density and highway, the transmission range per node increased, the end-to-end delay per message decreased, albeit at a faster rate up to moderate transmission range values of 500-600m and at a slower rate for larger transmission range values.

RNMDP incurs a relatively larger delay compared to flooding for all the simulated scenarios (Figures 11.5 and 11.6). RNMDP suffers a Rebroadcast-Wait-Time delay at each node before transmission from the node. Nevertheless, RNMDP suffers an end-to-end delay per message that is no more than 35% of the delay suffered by flooding in almost all the scenarios. The only scenarios for which the RNMDP end-to-end delay per message delivered is significantly greater than its flooding counterpart are the low lane density networks with a smaller transmission range, where the Rebroadcast-Wait-Time is relatively larger. Even in these scenarios, RNMDP effectively make use of the addition of the second lane to improve the message delivery ratio compared to highway with single lane.

14.0 Conclusions

RNMDP incurs relatively much lower energy consumption for delivery of the Risk Notification Messages compared to that incurred with flooding. RNMDP does not require periodic beacon exchange and conserves network bandwidth. Simulation studies illustrate that the Rebroadcast-Wait-Time does not significantly increase the end-to-end delay for the messages delivered. With a slightly larger delay (i.e., no more than 35% of the delay incurred for flooding), RNMDP can achieve the same message delivery ratio attained by flooding, but at a relatively much lower energy loss compared to flooding. RNMDP performs exceptionally well in high lane density networks incurring the least possible energy consumption with a delay very closer to that incurred with flooding. Also, in networks of low lane density, RNMDP efficiently makes use of the increase in the number of lanes by allowing nodes traveling in lanes in the direction away from the Risk Zone to rebroadcast the RNMs, albeit with a higher Rebroadcast-Wait-Time.

15.0 Related Work

As a supplemental part of this research, graduate students also initiated work focusing on the development of a small, lightweight, easily deployable wireless traffic density counter to capture data and aid in the management of traffic flow. The measurement of traffic volume is a fundamental function of highway planning and management; and traffic volume counts provide one of the most common measures of traffic engineering analysis. This novel network of wireless sensors may offer greater flexibility and lower maintenance than prior technologies. Furthermore, the system does not require the collection of precise traffic counts; but instead relative counts representing light, moderate and congested traffic flows.

The following factors were considered: type of sensors, type of wireless transmitting device and deployment methods. The sensors evaluated included Hall Effect, magnetic proximity, ultrasonic and passive infrared (PIR). The wireless devices considered included Archrock Wireless Sensor Nodes, Rabbit Technologies, Zigbee Application Kit, and the Texas Instruments MSP 430 eZ430-RF2500 Development Tool. The data acquired included number of vehicles, speed, size, and type. Deployment methods included fastening the unit to the road, embedding it in the road, mounting under a bridge, or mounting on a roadside sign.

To take advantage of low-power consumption, researchers selected passive infrared sensors connected to a TI MSP430 wireless device mounted on a roadside sign. The sensors were designed to measure speed and count the number of vehicles. Next, researchers built a test circuit based on logic gates. The circuits used one PIR to both start and stop the counter. After the counter was stopped, the LED was either on or off, indicating a binary number combination that could then be translated into a decimal number and converted to miles per hour. The reaction of the PIRs and count were consistent based on laboratory conditions.

The team designed the system to be relatively inexpensive and require minimal set-up or calibration. Future work could focus on integrating the traffic density counter outputs into a geographic information system to provide a means of visually monitoring major transportation corridors and secondary routes. Such a system could employ fuzzy logic and/or another decision support tool to provide planners and emergency management personnel with new opportunities for roadway monitoring and traffic surveillance system.

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Dr. Natarajan Meghanathan, Assistant Professor in the Department of Computer Science at Jackson State University, is actively pursuing specialized protocols for wireless sensor networks and, in particular, mobile aspects of wireless communications.

Kenneth Swan, while working as an undergraduate research assistant at CDID, performed the core research on the traffic density sensor. Following that research, Kenneth collaborated with Oak Ridge National Labs in furthering the sensor development. He is currently employed by the Jackson State University Computer Engineering Department as a Research Associate.

Venu Peddireddy, Graduate Student in Computer Engineering, is continuing efforts on the wireless communications aspect of the traffic density sensor.

The results of the research, "An Energy Efficient Risk Notification Message Dissemination Protocol for Vehicular Ad hoc Networks" will be published in the 2009 Proceedings of the International Conference on High Performance Computing, Networking and Communication Systems.

17.0 References

[1] M. Rudack, M. Meincke, K. Jobmann and M. Lott, "On Traffic Dynamical Aspects Inter-vehicle Communication," *Proceedings of 57th IEEE Semiannual Vehicular Technology Conference*, April 2003.

[2] S-Y. Ni, Y-C. Tseng, Y-S. Chen and J-P. Sheu, "The Broadcast Storm Problem in a Mobile Ad hoc Network," *Proceedings of 5th Annual ACM/IEEE International Conference on Mobile Computing and Networking*, pp. 151-162, August 1999.

[3] R.W. Rothery, "Car Following Models," *Traffic Flow Theory*, Transportation Research Board, Special Report 165, 1992.

[4] B. Hofmann-Wellenhof, H. Lichtenegger and J. Collins, *Global Positioning System: Theory and Practice*, 5th rev. ed., Springer, September 2004.

[5] E. Fasolo, A. Zanella and M. Zorzi, "An Effective Broadcast Scheme for Alert Message Propagation in Vehicular Ad hoc Networks," *Proceedings of IEEE International Conference on Communications*, Vol. 9, pp. 3960-3965, June 2006.

[6] O. Tonguz, N. Wisitpongphan, F. Bait, P. Mudaliget and V. Sadekart, "Broadcasting in VANET," *Proceedings of Conference on Mobile Networking for Vehicular Environments*, pp. 7-12, May 2007.

[7] T. Osafune, L. Lin and M. Lenardi, "Multi-Hop Vehicular Broadcast (MHVB)," *Proceedings of 6th International Conference on ITS Telecommunications*, pp. 757-760, June 2006.

[8] IEEE 1609 – Family of Standards for Wireless Access in Vehicular Environments (WAVE), U.S. Department of Transportation, January 9, 2006.

[9] IEEE 802.11-2007: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

[10] L. M. Feeney, "An Energy Consumption Model for Performance Analysis of Routing Protocols for Mobile Ad hoc Networks," *Journal of Mobile Networks and Applications*, Vol. 3, No. 6, pp. 239-249, June 2001.