Pothole Detection and Warning System: Infrastructure Support and System Design

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Abstract

Many on-going projects in the field of vehicular networks are working in the direction of providing driver with relevant information about roads and traffic movements. In this paper, we propose a novel Wi-Fi based architecture for Pothole Detection and Warning System which assists the driver in avoiding potholes on the roads by giving prior warnings. The system consists of access points placed on the roadsides for broadcasting data, which can be received by the Wi-Fi enabled vehicles as they enter the area covered by the influence of the access points. The mobile nodes can also broadcast their response as feedback which when received by access point can be utilized for backend server processing.

The pothole detection application proposed in this paper enables the driver to receive information of the potholes on the roads in the vicinity of the moving vehicle. The application can be integrated in the vehicle so as to alarm the driver in the form of a visual signal, audio signal or even trigger the braking system. Simulations demonstrate the advantages of using our approach for constructing pothole detection systems. Many such similar applications can be deployed over the framework provided by the system to assist navigation on roads.

1. Introduction

Traffic congestion has been increasing world-wide as a result of increased motorization, urbanization, population growth and changes in population density. Congestion reduces utilization of the transportation infrastructure and increases travel time, air pollution, fuel consumption and most significantly, traffic accidents. While different factors contribute to vehicle crashes, driver behavior is considered to be the leading cause of around 95% percent of all accidents. The driver behavior can be improved by either alerting him about the probable collision or controlling the vehicle itself.

At present, the commercially available traffic detecting equipments include loop detectors, pressure sensors, infrared, radar, ultrasound based sensors and video cameras. Although loop detectors are cheap to manufacture, their installation and repair are very expensive because they involve digging and re-surfacing of the road, which is labor intensive, time consuming and causes disruption to the traffic. The pressure based traffic sensors have the same problem. Infrared, radar and ultrasound sensors, on the other hand, are more expensive to make. The use of these active devices in urban areas may have safety and other regulatory implications. The effectiveness of this type of sensors can also be affected by bad weather. Also the images have to be processed further to obtain useful data from them.

There is an increasingly number of on-going projects aiming to extract objective traffic condition indicators from the video images. But the huge volume of data involved in these video images indicates that such systems require substantial computation power, and consequently, will not satisfy the aim of producing low cost devices for a considerable period of time. Finally, GPS based systems have very high operational costs as they need to obtain the precise positions of the vehicles in every few milliseconds.

The rest of the paper is organized as follows: The infrastructure design and system support of the pothole detection system are discussed in Section 3. The simulations we carried out are shown in Section 4. Finally we present conclusions and future work.

2. Related Work

Homji [1] in his intelligent pothole repair vehicle uses a mechanical arrangement consisting of a wheel attached to a spring. When the wheel passes through a pothole, the deflection in the spring is measured by an optical shaft encoder. Depending on the reading, the depth of the pothole can be predicted. But the mechanical approach used in this system is hardly useful on high speed vehicles. Karuppuswamy [2] in his project used a vision based approach which calculates the histogram of the road environment. Based on the histogram, the vehicle could detect exact location of simulated potholes of circular size and diameter more than 2 feet. But this approach has

been tried only on simulated potholes. Also, this approach involves vision sensors with high response time.

Another approach used by Zoysa [3] is based on the vibration measurement using accelerometer. In this approach the sensor measures the vibration caused while passing through a pothole. We have tailored this approach to suit our pothole detection system.

The problem with all the above approaches is that they only concentrate on collecting the data. Our approach collects as well as distributes the data to other vehicles, so that it can be used by drivers in avoiding those potholes.

3. System Design and Infrastructure Support

In this section, we propose to design an infrastructure enabling the mobile nodes (vehicles) to get the information of the road conditions in their vicinity. This information will be passed down to the mobile nodes in the form of packets, which will be broadcasted by the access points. Figure 1 shows the basic system design with a single access point on the road and mobile nodes passing on both the sides. The access point will be broadcasting packets over UDP, which will not require any connection setup phase. As and when the mobile nodes come under the influence of the access point, they can receive a packet. It might happen that the first few packets may be garbled, but assuming the high packet broadcast rate for the access point, the mobile node will receive packets successfully.

Figure 1: System design showing an access point and Wi-Fi equipped vehicles moving on both the sides

As the packets had relevant information about the road conditions in the vicinity, the driver can be warned by using a beep or visual signal if a pothole is present in the vicinity. If the road condition is very poor or extremely dangerous, the application on the vehicle can trigger the braking system to slow down or halt the car to avoid any mishaps.

The mobile nodes can also send packets to the access points as feedback. The packet contains details such as its own identification code, the location estimates and the validity of the potholes' information. This packet once received by the access points is sent over the backend server for processing. When the packet reports that the pothole was not

detected, the server can forward this information back to the access point. This information can then be used to update the information at the access points, such that the false positives can be removed. In case the information contained in the packet indicates that a pothole was observed where the system had not yet indicated to the vehicle, then it can add this information in the access points. In this way, the system can learn from itself as the time progresses.

During the setup phase of the access points, each of them would be given correct location co-ordinates using a GPS device. This would have to be done only once, until the access points are not shifted. Therefore, this does not load the system with heavy training phase unlike the other location estimation systems and hence clearly qualifies for a metropolitan wide deployment and use. The packet that is broadcasted by the access point contains the location information which in-turn can help the mobile node to estimate its own location.

The Wi-Fi standard leaves connection criteria and roaming totally open to the client. This is the strength of Wi-Fi, but it also means that one wireless adapter may perform substantially better than another. Since Wi-Fi transmits in the air, it has the same properties as a non-switched wired Ethernet network, and therefore collisions may occur. Unlike a wired Ethernet, and like most packet radios, WiFi cannot do collision detection, and instead uses a packet exchange (RTS/CTS used for Collision Avoidance or CA) to try to avoid collisions. But researches [4] show that the use of such overhead reduces the throughput of the system and it would be advisable to design the system where the environmental settings are known. So by avoiding the use of RTS/CTS we are increasing the chances of collision, and the packet being garbled, but on the other hand we are reducing the overhead and increasing the probability that the information packet can be received in real-time.

In other words, it would be a replacement for signs, billboards and markers, and perhaps much more. The benefit of using this technology is its dynamic property. We can modify the information stored in the access points from the connected servers. Using this system design, many applications similar to pothole detection can be deployed over the framework to assist navigation on roads.

4. Simulation Experiments

Simulations were performed on Qualnet 4.0, which is distributed by Scalable Network Technologies [5]. The experiments involved the mobile nodes (i.e. vehicles equipped with Wi-Fi) driving past an access point. The experimental setup was designed to test

and verify the effects of the speed of the mobile nodes, density of mobile nodes under the influence of the access point, application layer packet size and the rate of broadcast from the access point, on the number of application layer successful transmissions.

4.1 Effect of speed and packet size

This section describes about the experiments conducted to study the effects of the speed of mobile nodes and the application layer packet size on the number of successful transmissions of the packets. The experimental setup includes 36 mobile nodes, broadcasting packets at the rate of 1 packet in 10 seconds while the access point is broadcasting packets at the rate of 1 packet per second. The reason for setting up this scenario is that it satisfies the information model in which the mobile nodes should receive more data, as they pass through the access point rather than access point hearing data from the mobile nodes.

The average speed of the mobile nodes was varied from 30 km/h to 180 km/h in the difference of 30 km/h. Hence, the tests could comment on the feasibility of the system in multiple scenarios, including slow city traffic to highway traffic. The experiments also include the study of change in packet size on the number of successful transmissions. By varying the packet size we could conclude the versatility of the system, as per the amount of data that it can send. The packet size was varied in from 500 Bytes to 2000 Bytes, in steps of 500 Bytes.

Figure 2 depicts the average number of packets received correctly by the mobile nodes from the access point. As per our analysis before the experiment, the nodes moving at the speed of 30 km/h would cross the access point's influence in about 90 seconds. During that time, the access point would have broadcasted nearly 90 packets. And if the channel between the node and the access point would be free for that time, the mobile node should receive the packet successfully. As the nodes are also sending packets at the rate of 1 packet every 10 seconds, it implies that some of those packets would be garbled. Therefore, the experimental results match the results of our analysis. The results for the higher speeds also follow the same trend.

The graph in Figure 3 shows the average number of packets received correctly by the access point from each of the mobile nodes. As per our analysis, in 90 seconds, the mobile node will try to send maximum 9 packets at the same rate but the presence of other mobile nodes (which are also probably trying to send packets at the same rate) causes interference and drops the number down to

nearly half of it. The results for the higher speeds also follow the same trend.
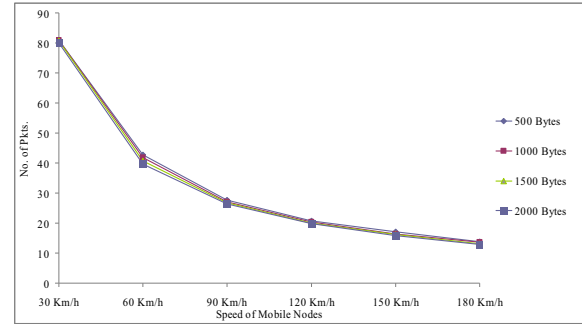

Figure 2: Average number of packets received by each mobile node from access point at different speeds and packet sizes
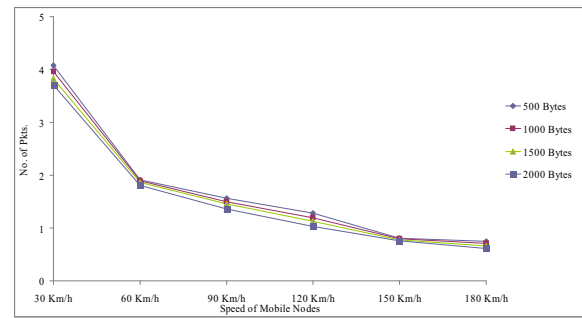

Figure 3: Average number of packets received by access point from each of the mobile nodes at different speeds and packet sizes

The graphs in Figures 4 & 5 depict the trend of the number of packets received while changing the packet size.
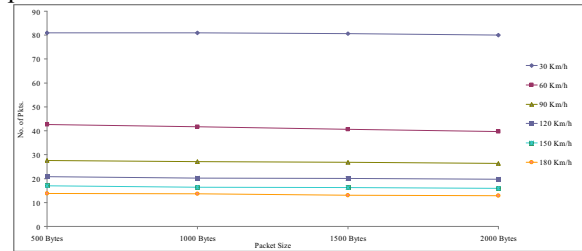

Figure 4: Average number of packets received by each mobile node from access point at different packet sizes and speeds
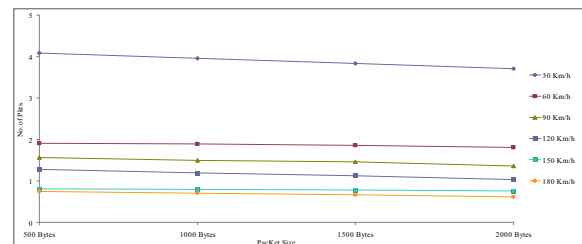

Figure 5: Average number of packets received by access point from each of the mobile nodes at different packet sizes and speeds

It can be concluded from the above results that the speed of a mobile node has direct relationship with the amount of time it spends in the influence of the access point and hence directly influences the number of packets it receives. The packets received by the access point also follow the same trend. It can also be inferred that change in packet size has negligible effect on number of packets received by mobile nodes or the access point.

3.2 Variation of speed and packet rate at access point and mobile node

The experimental setup for this section is similar to that of previous section. Figures 6 & 7 indicate the effect of speed of mobile nodes and packet broadcast rate on the number of successful packet received.
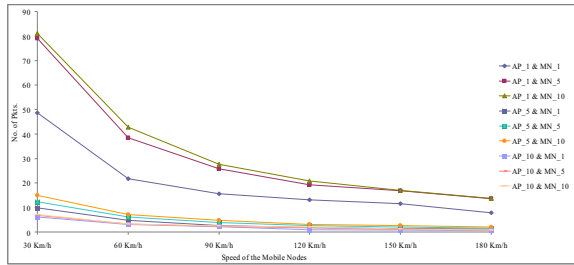

Figure 6: Average number of packets received by each of the mobile nodes from the access point at different speeds and packet rates
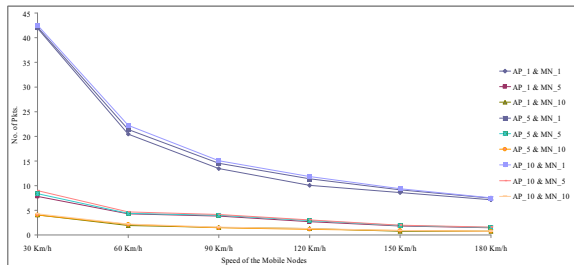

Figure 7: Average number of packets received by the access point from each of the mobile nodes at different speeds and packet rates

It can be inferred from the above graphs that as the packet rate at the mobile nodes drops, the number of packets that are able to get free channel, is increased by the same factor. The same trend continues with lower rates of the transfer from access point.

4.3 Variation of number of mobile nodes and packet rate at mobile node

The number of mobile nodes in this experiment was varied as 4, 12, 36, 68 and 132 nodes. Hence the tests could comment on the feasibility of the system in a range of scenarios, including sparse traffic to moderate traffic and even the worst case jam conditions. The experiment also includes the study of change in packet rate, at the mobile nodes, on the number of successful transmissions.

The experimental setup includes mobile nodes moving at an average speed of 60 km/h. The access point is broadcasting packets at the rate of 1 packet per second. The packet size is fixed at 500 Bytes. The mobile nodes are broadcasting packets of 500 Bytes at each of the packet rates.

Figure 8 depicts the average number of packets received correctly by the mobile nodes from the access point. According to the experimental analysis, the nodes moving at 60 km/h would cross the access point's influence in about 45 seconds. During that time, the access point would have broadcasted nearly 45 packets. If the channel between mobile node and the access point would be free for that time period, the mobile node should receive the packet correctly. As the nodes are also sending packets at 1 packet per second, this means that most of the packets would be facing interference. However, this interference is directly proportional to the number of mobile nodes in the influence. Therefore, as the number of mobile nodes increases, number of packets that can be correctly received by the mobile nodes reduces by the same factor.
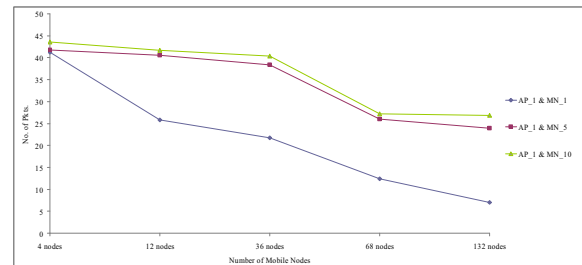

Figure 8: Average number of packets received by each of the mobile nodes from the access point at changing the number of mobile nodes

The graph of Figure 9 shows the average number of packets received correctly by the access point from each of the mobile nodes. According to the analysis, in the same 45 seconds of travel, the mobile node would be trying to send a maximum of 45 packets, at that rate, but the crowd of other mobile nodes which are also probably trying to send packets at the same rate causes interference and drops the number of packets being transferred. The effect of increase in the number of mobile nodes from 4 to 132 is the decrease in the number of successful packets to the access point being reduced up to four times. The results for the lower packet rates also follow the same trend.
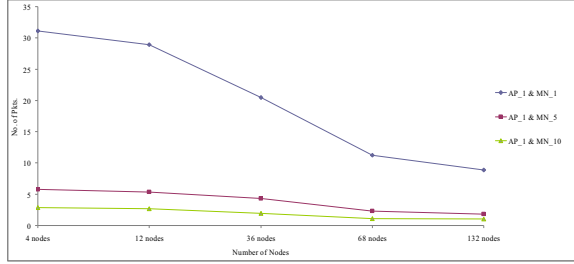
Figure 9: Average number of packets received by the access point from each of the mobile node at changing the number of mobile nodes

When the mobile nodes are transmitting at a high rate like 1 packet per second, there is a steep downfall in the number of packets received by each of the mobile nodes.

The graphs below in Figures 10 & 11 depict the trend of the number of packets received with changing the packet rate.
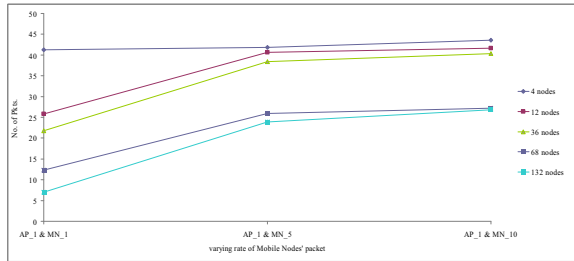

Figure 10: Average number of packets received by each of the mobile nodes from the access point at different packet rates for the mobile node keeping the number of mobile nodes fixed
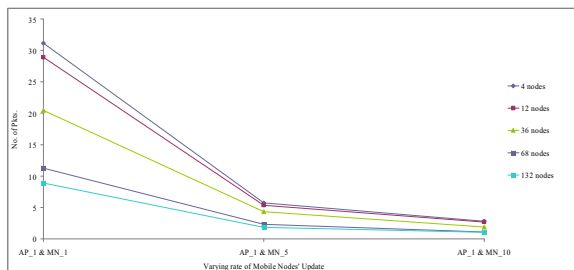

Figure 11: Average number of packets received by the access point from each of the mobile node at different packet rates for the mobile node keeping the number of mobile nodes fixed

It is inferred that the number of mobile nodes has a direct influence on the number of packets that each node receives. The packets received by the access point also follow the same trend. Another conclusion that can be drawn is that change in packet rate at the mobile node also inversely relates to the packets that it receives correctly. Also, with lower number of nodes, the number of packets received by each node remains unaffected by the change in the packet rate of the mobile nodes.

5. Conclusions and Future Work

In this paper, we consider the problem of designing a novel Wi-Fi based infrastructure enabling application data transfer to the vehicles moving on the roads. This system can assist the driver in making strategic and real-time tactical decisions in varied environments. The detailed system design described in the paper explains the functions of two main components, access points and Wi-Fi equipped mobile nodes. The architectural design and system support for the pothole detection and warning system ensured that the driver gets information about potholes well in advance and has sufficient time to take decision according to the prevailing road conditions.

We plan to extend this project to accommodate further information about road such as traffic congestions, public announcements, location specific information, etc. as part of our future work.

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