The Future of Traffic Information Systems

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ABSTRACT – Traffic congestion has always been a serious problem for people in the big cities around the world. It causes unpleasant and unpredictable delay. Knowing the traffic condition in advance helps the drivers plan their trips wisely. Moreover, having real-time traffic information at hand, the drivers can adjust their route selections on-the-fly. This helps the drivers avoid entering the congested areas. Obviously, the traffic information plays an important role in alleviating the traffic problem. Currently, there are many methods used for collecting and distributing the traffic information. This article provides an in-depth review of these methods. In addition, the future traffic information systems and the challenges ahead will also be discussed.

KEY WORDS – Traffic information systems, vehicular ad hoc networks, intelligent transportation systems

1. Introduction

Traffic congestion has always been a serious problem for commuters in the metropolitan areas around the world. It causes unpleasant and unpredictable delay. In Bangkok, for example, when the traffic is congested, it typically takes commuters additional 1-2 hours to complete their journeys. Congestion not only wastes the valuable time, but also the fuel energy and other precious resources. The loss due to congestion is quite costly (i.e., on the order of billion dollars annually [1]).

There are a number of solutions proposed for alleviating the congestion problem. However, they can generally be divided into two categories: (i) a long-term solution and (ii) an immediate solution. A long-term solution aims at reducing the number of vehicles on the road. Obviously, if the number of vehicles decreases, the traffic should be less congested. Typical solutions in this category include building new public transportation systems, taxing privately owned vehicles, and limiting the number of vehicles per household. However, a long-term solution usually takes quite a while to accomplish.
For example, it takes years to build a new public transportation system such as a subway. In contrast, an immediate solution aims at relieving the congestion on a shorter time scale. A good example of the immediate solution is dynamic re-routing, where drivers react to congestion by taking an alternative less congested route based on the traffic information they receive. Obviously, this type of solutions would require a traffic information dissemination system.

A good traffic information dissemination system is one of the keys to solving the congestion problem. One of the main reasons why congestion persists is that drivers hardly have sufficient time to react when it occurs. Frequently, drivers are unnecessarily stuck in the traffic on a congested street although they could have taken other alternative routes. This is mainly due to the lack of traffic information. Had the traffic information been available to the drivers well in advance, they would be able to make a better decision by avoiding the congested areas. A number of surveys also show that drivers are willing to take alternative routes to avoid congestion if they have prior information about the traffic condition [2–4]. Clearly, accessibility to an accurate and timely traffic information can help alleviate the congestion problem. The merit of the traffic information, however, depends on the effectiveness of the traffic information dissemination system. In this article, we will discuss the advantages and the disadvantages of various kinds of traffic information dissemination systems.

The remainder of this article is organized as follows. In Section 2, we review the current traffic information dissemination systems. In Section 3, we discuss the future distributed self-organizing traffic information dissemination system. In Section 4, we discuss the research directions and the challenges in developing a self-organizing traffic information dissemination system. Finally, we briefly summarize this article in Section 5.

2. Current Traffic Information Systems

The effectiveness of information distribution depends on a well-designed traffic information dissemination system. A traffic information dissemination system consists of the following three functions: (i) data collection, (ii) data processing, and (iii) information dissemination. In the following subsections, we review the methods and techniques used in performing each of these functions in the current traffic information systems.

2.1 Data Collection

Data collection is an important function of a traffic information dissemination system. Certainly, the data collection process will affect the accuracy and the reliability of the traffic information. A wide variety of techniques have been used in data collection.

1) Human Input: Human input is probably the most primitive and the simplest method in collecting traffic data. In this method, actual drivers on the streets will contact the call center and report the current traffic conditions at their respective locations. The traffic report is typically done via a cellular telephone call. However, given the current technology, the report could also be done through Short Message Service (SMS) [5] or Multimedia Message Service (MMS) [6]. In other words, drivers could also convey the traffic information to the collection center through text messages, photos, or video streams. The types of traffic information that the drivers provide the call center may include the congestion level, the vehicle density level, the road condition (e.g., slippery, icy, flood, etc.), and the traffic incidents. The human input method is usually used by a traffic radio station, for instance, FM 100 MHz in Bangkok.

Although this data collection method is cheap and simple, it has some disadvantages. First, the data reported by a human may not be accurate. Since the data reported by each driver is based purely on the driver's own opinion and judgment, it is difficult to verify the accuracy of the information provided. In addition, each driver has different perception about the traffic condition. For example, a street where vehicles move with an average speed of 20 km/hour may be considered as "very congested" for one driver, but it may be considered as "moderately congested" for another driver on the same street. Thus, the traffic information collected by this method may not be accurate. Reliability also becomes an issue. Since the traffic report is sent to the call center on a voluntary basis, the traffic conditions in the areas where there are no volunteers to submit the reports will not be available. In addition, the frequency of information updates is also unpredictable since the call center never knows when a driver will call to report. This makes the human input method unreliable.

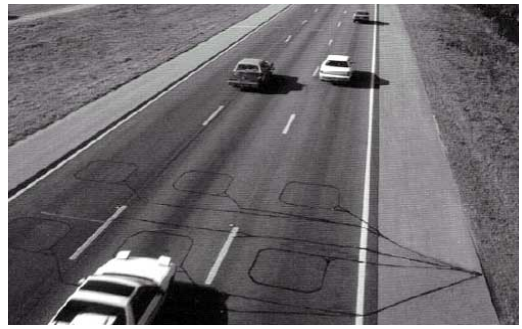

Figure 1. An example of the inductive loop detectors embedded under the road surface. Image source: Federal Highway Administration.

2) Inductive Loop Detectors: In this data collection method, the traffic data are collected by the sensors called "inductive loop detectors." An inductive loop detector (ILD) is a sensor which is implanted under the road surface [7]. An example of the ILD is shown in Fig. 1. When an object (e.g., a vehicle) passes over or lays on top of the ILD, it changes the inductance of the loop. The change in the inductance indicates the presence of an object, and the knowledge of the presence/absence of an object can be used for vehicle counting. In addition, the ILDs can also be used for estimating the vehicle speed. Generally, the vehicle speed can be estimated either by using a single ILD or double ILDs. With a single ILD, the speed is normally estimated by the following expression [8]

$$v = \frac{l}{T} \tag{1}$$

where v is the estimated speed, l is the effective length of the vehicle, and T is the duration that the vehicle stays on top of the ILD (i.e., passage time). In the case of double ILDs, two detectors will be installed at two separate points. These two detectors are sometimes referred to as "the speed trap" [9]. In this case, the vehicle speed can be estimated by the following expression

$$v = \frac{d}{t_2 - t_1} \tag{2}$$

where v is the estimated speed, d is the distance between the two detectors, t_1 is the instant at which the vehicle passes through the first detector, and t_2 is the instant at which the vehicle passes through the second detector. Normally, the time at which the vehicle passes through each detector is sent to the central processing unit, and the estimated vehicle speed is computed there.

The ILD is quite accurate in providing the vehicle counts. It is claimed that the ILD has approximately 0.8 percent error, even in the presence of crosstalk [10]. However, the main disadvantage of the ILD is that it is not convenient to install, especially after the road had been paved.

3) Surveillance Cameras: In this data collection method, cameras are installed at various locations to capture the current traffic condition. The video stream from each camera will be relayed to the data collection center. This method is frequently used in real-time traffic monitoring. The information that could be extracted from the video frames includes the estimated vehicle density, the estimated vehicle speed, and the vehicle identity [11–22]. Clearly, accuracy and reliability of the traffic information acquired by this approach will depend largely on the quality of the captured images/videos as well as the image processing techniques used in extracting the traffic information. The image/video quality (e.g., image resolution) is subject to the capability of the cameras. Based on the current advance in surveillance technology, capturing a sufficiently high resolution image is not really a major problem. Consequently, most of the research in this area has focused more on the algorithms for extracting the traffic information from the images/videos.

The image/video processing algorithms for extracting the traffic information can generally be divided into two categories: (i) feature tracking algorithms, and (ii) counting-based algorithms. The feature tracking algorithms aim at identifying a moving vehicle through a sequence of images or video frames [14–19]. By tracking the positions of a particular vehicle in the consecutive video frames, it is possible to determine the distance that the vehicle moves. The vehicle speed can thus be estimated by the following expression

$$v = \frac{z}{t_{f2} - t_{f1}} \tag{3}$$

where v is the estimated speed, z is the estimated distance that the vehicle moves, t_{f1} is the instant at which the first video frame is captured, and t_{f2} is the instant at which the second video frame is captured.

As opposed to the feature tracking algorithms, the counting-based algorithms aim at counting the number of vehicles passing through a reference point in the image. This idea is quite similar to that of the inductive loop detector, and thus it is usually referred to as the “virtual loop detector.” Basically, the number of vehicles is estimated by detecting the presence of the vehicles at the reference point in the image. Determining the number of vehicles that passes through the reference point allows one to estimate the vehicle density, the average traffic flow rate, and the average vehicle speed [20–22]. In general, the counting-based algorithms are less complex than the feature tracking algorithms. However, the counting-based algorithms usually require higher level of human interaction and are less flexible than the feature tracking algorithms [13].

4) Probe Vehicles: In this method, designated vehicles on the road will be acting as probes or sensors for collecting various traffic data [1, 23–31]. A probe vehicle is basically a normal vehicle equipped with a special apparatus for collecting and transmitting data. In most cases, each probe vehicle is also equipped with an on-board Global Positioning System (GPS) receiver [32]. Generally, a number of probe vehicles will be deployed on various road sections in order to provide a broad coverage. While a probe vehicle is traveling along a road section, it will collect various types of data, for instance, its location, its speed, and its travel time. The collected data will be periodically sent to an information sink, such as a roadside unit or the data collection center, for further processing and distribution. The probe vehicles method has recently attracted a lot of attentions from the intelligent transportation systems (ITS) research community, due to its flexibility and versatility. It allows a lot of freedom in implementation. In fact, the system designer has the liberty of choosing:

- **Type of probe vehicles—**While a probe vehicle can be any vehicle on the street, among the popular choices are taxi cabs and buses [23, 30, 33]. For example, it is reported that approximately 2,000 taxi cabs serve as the probe vehicles in Beijing [23], and more than 10,000 taxi cabs are used for the same purpose in Singapore [30]. In Portland, Oregon, each transit bus is equipped with a Bus Dispatch System, which enables the bus to record the arrival and departure times at each stop as well as the maximum instantaneous speed attained between the stops [34]. Although different types of vehicles have been used as mobile probes, currently there is no direct comparison regarding the effectiveness of each type of probe vehicles.
- **Type of collected data—**There are many types of data that the probe vehicle can collect. Obviously, the instantaneous speed of the vehicle can be measured at any time. With an on-board GPS receiver, the vehicle location can also be traced throughout its entire trip. The total travel time can also be collected. In addition, various kinds of sensors (e.g., temperature sensors, light sensors, pressure sensors, etc.) are now common parts of the new automobiles. Data collected from these sensors are also helpful in providing more accurate traffic information. For example, if the temperature is below the freezing point and

it is raining, then there is a good chance that the road might be slippery or icy.

2.2 Data Processing

In this phase, the collected traffic data will be processed and interpreted by the data processing unit, which is the brain of the traffic information dissemination system. How well the processed data reflect the actual traffic condition depends on the effectiveness of the data processing algorithms. Each kind of traffic data, of course, requires its own processing technique. For example, estimating the average vehicle speed on a road section from a video stream will require an image/video processing technique [11–22]. Similarly, estimating and predicting the link travel time will require the travel time estimation technique [35–39]. Regardless of the types of data, however, the processing is generally done in one of these two ways:

- **Centralized processing—**The centralized processing model is currently employed in most traffic information dissemination systems. This is due to the fact that, in most systems, each data collection unit relays the traffic data directly to the central data processing unit. One advantage of this scheme is that the central processing unit will have a global knowledge of all the information. This makes it convenient to process and check for inconsistency.
- **Distributed processing—**In this model, there is no central unit for processing the traffic data. Each individual user processes and interprets the data by itself. This is a typical model used in an ad hoc wireless network. More details regarding an ad hoc wireless network will be presented in Section 3.

2.3 Information Dissemination

After the traffic data have been processed, they will be distributed to the drivers. In this subsection, we review the techniques currently used in disseminating the traffic information.

1) Radio Broadcast: Radio broadcast is one of the most primitive methods in disseminating the traffic information. It has been around for many years. In this method, the traffic conditions at various locations in the city are broadcast via FM radio. The main advantage of this scheme is that the radio has a large coverage range. As a result, the broadcast information can reach almost everywhere in the city. In addition, most vehicles are already equipped with FM receivers, so the drivers do not need to buy any new equipment. However, the traffic information broadcast via the radio may not be effective because the broadcast information is not customized to serve each specific group of drivers. For example, the drivers on Street A may not need to know the traffic condition on Street B, where Street B is 100 km away from Street A. Instead, the drivers on Street A are more likely to be interested in the traffic condition on Street C, where Street C is two blocks away from Street A. Moreover, with this method, the drivers do not know when the traffic conditions in their interested areas will be reported. Consequently, the drivers will not have real-time accessible traffic information. Ultimately, the major problem of the radio broadcast method is that the right information may not be delivered to the right people at the right time.

Figure 2. An example of a dynamic message sign. Image source: imsasafety.org.

2) News Feed: In this scheme, a driver has to subscribe to a news feed (e.g., a traffic report), and the traffic information will be periodically sent to his/her mobile device such as a cellular phone or a personal digital assistant (PDA). This method is generally good for broadcasting the traffic incidents. However, similar to the radio broadcast, the information distributed by this method may not be tailored enough to serve a specific group of drivers.

3) Dynamic Message Signs: A dynamic message sign (DMS) is an electronic board for displaying the traffic conditions. The information displayed on the DMS may include the congestion level, the vehicle density, the estimated travel time, and the traffic incidents. The DMS is widely used in many major cities. In the United States, there are more than 4,500 DMS installed [40]. It is also reported in [40] that drivers generally have positive experiences with DMS. An example of the DMS is shown in Fig. 2.

The DMS usually displays only the traffic condition of the street where it is installed and that of the nearby streets. Thus, in this sense, the traffic information is customized specifically for the drivers on these streets. This is an advantage over the radio broadcast method because only the relevant information is conveyed to the drivers. However, the DMS also has a limitation. That is each driver needs to have a direct line-of-sight to the DMS. Drivers that are too far away from the DMS will not be able to access the information. This limits the range at which the information can be disseminated, and thus by the time the drivers get the information, it might be too late to react to the traffic condition such as congestion.

4) World Wide Web: The World Wide Web (WWW) access is a convenient way for distributing the traffic information. Various traffic information such as the travel time, the average vehicle speed, the real-time traffic images, and the construction closures, can be put on a website. With the internet access, the drivers could pre-plan their routes based on the available traffic information before leaving home. Alternatively, the drivers could also plan their routes dynamically as they go, by using their cellular phones to access the traffic report website. Some examples of the traffic report websites are Traffy (www.traffy.in.th) and Longdo (traffic.longdo.com).

Reporting the traffic condition through the World Wide Web has an advantage over the other methods since the information is accessible on-demand. However, accessing the traffic information from the website while driving may distract the drivers and thus poses a serious safety concern.

3. The Future Traffic Information Systems

Over the past few years, an ad hoc wireless network has emerged as a new paradigm of wireless communications [41–43]. As opposed to the centralized cellular architecture where every transmission has to be coordinated by a base station, in an ad hoc communication model, devices can self-organize and form a network, without relying on the help from any central authority. The distributive nature of an ad hoc wireless network makes it easy and inexpensive to deploy, since no massive infrastructure is required. Due to its potentially promising applications, ad hoc wireless networking has recently gained a great deal of attentions from the research community.

One of the most promising applications of ad hoc wireless networks is the vehicular ad hoc network (VANET). In VANET, vehicles can create a network for exchanging information among themselves. Messages from one vehicle can be relayed to another distant vehicle in a multi-hop fashion. This is particularly useful for distributing traffic and safety information. For example, an emergency warning from a vehicle that has just witnessed an accident can be relayed to the other vehicles in the nearby area. Other useful information that could be exchanged among the vehicles includes the congestion level, the road condition, the weather condition, and the nearby gas stations. Distributing such information in VANET relies on a multi-hop routing/broadcasting algorithm.

Disseminating traffic information in VANET is a unique problem. In contrast to the traditional information, the traffic information generally has a broadcast-oriented nature. In other words, the traffic information is of the public interest. It usually benefits a group of people rather than a single individual. For example, knowledge of a traffic accident will be beneficial not only to a specific individual but also to other people near the accident site. Thus, instead of focusing on a unicast routing algorithm where each message is directed to a specific destination, the research in this area has concentrated more on multi-hop broadcasting, also referred to as “flooding,” strategies.

The main issue concerning broadcasting in VANET is scalability. In a general flooding algorithm, a source initiates a message and the other nodes in the network rebroadcast that message at least once. Thus, a single message will be duplicated at least n times, where n is the number of nodes in the network. This becomes a serious problem when the size of the network is large. In order to make the broadcasting scheme scalable (i.e., works on a network of any size), reduction of excessive broadcasting messages should be taken into account. There are smart flooding algorithms which aim at reducing the number of duplicated broadcast messages [44]. Reducing the number of redundant messages makes flooding more scalable. Readers are referred to [44] for more details on the smart flooding algorithms. Of course, the effectiveness of each algorithm comes at the expense of its complexity.

In addition to the scalability issue, broadcasting in VANET also suffers from a broadcast storm problem [45]. The nature of the problem can be described as follows. When a source node broadcasts a message, the message will reach all of its 1-hop neighbors. A severe contention and collision could occur if many of the neighboring nodes rebroadcast the message at the same time. This phenomenon is referred to as the broadcast storm. Generally, there are two ways to resolve this problem. One of the solutions is to reduce the number of unnecessary rebroadcast messages. This can be achieved by using the smart flooding algorithms mentioned earlier. The other solution is to add a random delay time before each node rebroadcasts the message to avoid the collision.

Furthermore, due to the unique characteristic of VANET, the medium access control (MAC) protocol and the physical layer (PHY) protocol also need to be modified. Similar to other wireless applications, there is also an effort to develop a standard air interface for inter-vehicular communications. In 1999, the Federal Communications Commission (FCC) allocated 75 MHz of spectrum in the 5.9 GHz licensed band for DSRC [46]. Therefore, the physical air interface must be designed to work properly in this band. Currently, the Wireless Access in Vehicular Environments (WAVE) working group is investigating the new variant of the IEEE 802.11 standard for VANET called 802.11p. The new 802.11p standard is designed with the vehicular application requirements, such as reliability and low latency, in mind [47].

4. Challenges and Research Directions

It is clear that a good traffic information dissemination system should have the following desirable properties:

- **Real-time Accessibility—**The traffic information should be accessible in real-time. In other words, necessary traffic information should be available to the drivers at their fingertips.
- **Relevance—**Only the relevant information should be delivered to the drivers. Unrelated and unnecessary information should be filtered out.
- **Early Availability**—The traffic information should be made available to the drivers as early as possible in order to allow a sufficient time for them to react.

In our perspective, we believe that using VANET for distributing traffic information will be a suitable framework, since all the desirable properties mentioned above can be achieved. First, each vehicle will be able to access the real-time traffic information provided by its peers. Second, the range of information propagation in VANET can be controlled, this makes it convenient to deliver only the relevant information (e.g., only the traffic condition of the nearby streets) to each vehicle. Finally, since the traffic information can be propagated through multi-hop broadcasting, distant drivers will be able to receive the traffic information well in advance. This will allow an ample time for the drivers to react to the traffic information they receive. In the following, we discuss the challenges and the possible research directions in various aspects of the future traffic information system design.

4.1 Data Collection

Out of several data collection schemes described in Section 2, the probe vehicle method seems to be the most compatible with the VANET architecture. As opposed to the existing systems where a probe vehicle uploads the collected data to the central server, in the VANET architecture, the probe vehicle will broadcast the collected traffic data to the other vehicles. Theoretically, any type and any number of vehicles in the network can be used as probes. However, in order to make the system scalable, we believe that the number of probe vehicles should be controlled. This will help limit the number of broadcast packets flooded in the network. Therefore, in our considered architecture, we believe that the vehicles should be divided into two types: (i) the reporters and (ii) the observers. The reporters are the vehicles that can initiate the information packets. Basically, these are the probe vehicles. Exactly how many reporters the system should have, in order to obtain accurate traffic information, is still an open question. The observers are the vehicles that observe the information packets. An observer has an option of rebroadcasting the packet it receives. The decision on whether to rebroadcast a particular packet depends on a number of factors such as the node density, the number of hops that the packet has already propagated, and the significance of the packet. Determining an effective decision function for an observer is also a challenging task.

Some of the possible research directions in data collection are:

- **The number of reporters**—While there are many studies on the number of probes required for acquiring an accurate traffic information in a centralized processing model [26, 28–30], only a few studies have been conducted for the ad hoc wireless network model [48, 49]. It is also challenging to develop an analytical model for estimating the number of required probes in VANET based on parameters such as the vehicle density, the coverage area, the vehicle speed, and the network connectivity.
- **Type of collected information—**Although there are many possible candidates for the information that the reporter could collect, the information should be simple and easy to obtain. We believe that the location of the vehicles around the reporter can be easily collected. The reporter can use its neighboring vehicles' locations to estimate other useful traffic information such as vehicle density and average speed.

4.2 Data Processing

As opposed to the centralized architecture where all the collected data are forwarded to the central processing unit, each probe vehicle in VANET may have to process the data by itself. In other words, the essential intelligence must be shifted from the central server to the distributed mobile probes and the vehicles. Processing traffic data in VANET is a lot more challenging (and more interesting) than that in the centralized architecture since each vehicle does not have a global view of the traffic condition. In other words, a mobile probe may only have partial information regarding the traffic condition. An algorithm is needed in order to extract an accurate information from the collected data.

4.3 Information Distribution

Distribution of traffic information in VANET relies on broadcasting/flooding of information from the source. As mentioned earlier, the main concern with broadcasting/flooding in VANET is scalability. The key design issue here is how to make the broadcasting algorithm reliable (i.e., an information packet reaches all the reachable nodes), while keeping the number of redundant or duplicated broadcast packets at the minimum. In addition, since the traffic information is location-dependent, the broadcasting algorithm also needs to take this factor into consideration.

In a self-organizing vehicular traffic information system, once a vehicle receives the information packet, it needs to decide whether to rebroadcast the information further or not. How a vehicle should make a decision is an interesting subject to explore. In the simplest case, one may use a hop count (or time to live, TTL) to limit the range of the information. If the hop count is used, then a vehicle will make a decision on whether to rebroadcast the packet based on the TTL value in the packet it receives. Alternatively, a more sophisticated algorithm which takes factors such as the node density, the relative position between the receiving vehicle and the source, and the time at which the packet is initiated, into account should be more effective. How to create a good decision function based on these factors is worth studying.

5. Summary

In this article, we have described the general architectures of the traffic information dissemination systems and reviewed a variety of techniques used in the current systems. Basically, a traffic information dissemination system consists of three important functional processes, which are data collection, data processing, and information dissemination. We have discussed the pros and the cons of various methods involved in each of these three processes.

Most of the current traffic information dissemination systems have a centralized architecture where all the collected data are forwarded to the central processing unit. However, in the future, we expect to see a distributed architecture. With the recent advance in ad hoc wireless communication technology, particularly the ongoing research and development in VANET technology, the distributed model of traffic information dissemination system will soon be realized. Ideally, the traffic information should be real-time accessible, relevant, and early available to the users. Using VANET for distributing the traffic information can achieve all of these desirable properties.

Nonetheless, shifting from the centralized architecture to the distributed ad hoc architecture brings a lot of new challenges. First, one needs to be concerned with the minimum number of vehicles required to form a connected network. Second, since there is no central server for processing the traffic data, all the processing must be done by the probes or the vehicles which may not have the global view of the traffic condition. Thus, more intelligence is needed for the distributed data processing. Finally, the information dissemination in an ad hoc architecture depends on a reliable and scalable broadcasting algorithm. Designing a broadcasting strategy that can compromise these two objectives requires a careful study.

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