VeMail: A Message Handling System Towards Efficient Transportation Management

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Abstract—In this paper, we propose an electronic mail system, namely VeMail, for handling messages between vehicles and Intelligent Transportation Systems (ITS), to improve the efficiency of transportation management. After elaborating the reasons of using Internet email as a basis of messaging for ITS, we describe the key components of the VeMail system, including mail server, mail client, and mail proxy. Considering the intermittent connectivity of vehicles to the mail server, we propose an optimal probabilistic message retrieval (OPMR) scheme for VeMail, in which each vehicle optimally selects an online period for email retrieval. Simulation is used to evaluate the performance and the results demonstrate that the proposed scheme outperforms the regular mail retrieval method in terms of the connection time with the mail server.

I. INTRODUCTION

Due to growing urbanization and environmental pressures, improving efficiency of road transportation has been increasingly pressing to alleviate transportation problems, including traffic accidents, congestions, and air pollution, among others, especially in the developing world. There has been increasing interest and significant progress in the domain of emerging Vehicular NETworks (VANETs)\(^1\), which target to incorporate wireless communications and informatics technologies into the road transportation system, enabling the evolution to next generation Intelligent Transportation Systems (ITS). By utilizing communications of vehicle-to-vehicle (V2V), vehicle-to-roadside (V2R), and vehicle-to-infrastructure (V2I)\(^2\), VANETs facilitate a myriad of attractive applications related to safety (e.g., collision detection and lane change warning), driving assistance (e.g., online navigation and smart parking [1]), infotainment (e.g., mobile office and music store), and traffic efficiency and management (e.g., real-time traffic notification and speed management [2]). With rapidly evolving concepts of building applications, not only can VANETs significantly improve the efficiency of ITS, but also revolutionize the in-vehicle experience of passengers.

Electronic mail, also known as email, is an effective way to exchange delay-tolerant digital messages among connected computers. We have witnessed the growing popularity of Internet email in recent decades. As a must-have Internet application, email is commonly used to send and receive messages world wide and has dramatically changed the way we work and live [3]. The email system works in a store-and-forward fashion. The email message is first sent to the email server of the sending user, which is responsible to store and deliver the message to the email server of the receiving user. On-demand access to its own email server is then performed by the receiving user for message retrieval. Such an asynchronous message exchange does not require the sending and receiving users to be online simultaneously.

Since ITS aim to perform overall management of road traffic and assist drivers with safety and other information, a working message handling system is required to exchange electronic data between vehicles and the transportation system. In this paper, we propose an electronic mail system for ITS, which is called VeMail, based on V2R and V2I communications of VANETs. The motivation of applying Internet email for message exchange in transportation systems is fourfold. Firstly, there is a need of generating a wide variety of messages by ITS to get the driver better informed and therefore improve the safety and efficiency; Secondly, some ITS messages are delay-tolerant, such as road maintenance notifications, and can be delivered in an asynchronous fashion; Thirdly, many traditional elements of transportation systems, such as traffic tickets, can be electronized and go paperless by means of email; Finally, it is more efficient to leverage Internet for message delivery, which is in widespread use. After the detailed description of the system, we propose an optimal probabilistic message retrieval (OPMR) scheme for VeMail, considering intermittent connectivity of vehicles for accessing the email servers. We believe that the always-on connection to the Internet for vehicles is not achievable in current stage. Simulation is used to evaluate the proposed scheme.

The remainder of this paper is organized as follows: we elaborate the discussion of applying Internet email for ITS message exchange in Section II. The detailed description of the VeMail system is presented in Section III. In Section IV, we propose the OPMR protocol and evaluate the performance. A brief literature review is given in Section V. Section VI concludes the paper.

II. VeMail: A Basis of Messaging for ITS

A. VeMail: Rationale and Motivation

The fundamental part of VeMail is the existing Internet email system and a usage of V2R and V2I communications for email message exchange. In face of inevitably frequent

\(^1\)To deemphasize the ad hoc nature of vehicular networks, we redefine the term VANETs, which is traditionally the acronym of vehicular ad hoc networks.

\(^2\)Roadside infrastructure or roadside unit (RSU) includes traffic light, street signs, roadside sensors, and the like, which is different from ”infrastructure” in V2I communication providing Internet access to vehicles.
message exchange between transportation systems and vehicles, a basic messaging system for ITS is an urgent need. We believe that VeMail is capable of serving as such a basis of messaging for improving the efficiency of transportation management. The reasons are elaborated from the following perspectives.

**ITS Services:** A wide variety of ITS services are built on communications between vehicles and remote servers of the ITS management center (IMC) [4]. However, not all the messages need real-time delivery\(^3\). Some ITS messages, such as traffic condition updates and road maintenance notifications, can be stored in the remote server until the connection to the vehicle is established for transmission. Therefore, it is quite naturally to adopt an email system to send these delay-tolerant messages. Furthermore, once the email system is available for messaging in ITS, some traditional elements of transportation systems, such as traffic violation tickets and parking payment receipts, can be electronized and go paperless for environmental concerns. In this sense, the email system is capable of catering to the needs of emerging ITS services.

**Connectivity:** A prerequisite of messaging in ITS is the connectivity between vehicles and the IMC. Vehicles can connect to the remote servers through the communication with RSUs or access infrastructure. However, in the current status and near future, having long-lasting connection to the infrastructure may not be realistic. The email system offers a way of messaging under intermittent connectivity: vehicles send messages to the system or retrieve messages from the system when the connection is on. It can be seen that the communication environments of current ITS are well fit with the asynchronism of email messaging.

**Implementation:** As an essential part of our daily life, Internet access is expected anytime and anywhere. Providing Internet access to vehicles can be envisioned not only to cater to the ever-increasing Internet data demand of passengers, but also enrich ITS services, such as online diagnosis and intelligent anti-theft, in which the servers can be on Internet cloud. A recent automotive executive survey [6] further predicts a convergence between the automotive and TIME\(^4\) industry. Vehicles can have access to the Internet through cellular base stations (BSs), or drive-thru Wi-Fi access points (APs). From the implementation perspective, it is feasible to deliver the messages through the use of Internet rather than by building a new system without the consideration of the existing ones.

**B. Examples of Applications**

Some examples of applications supported by VeMail system are given in the following.

**Location-specific Service:** The vehicle can automatically send a message by using VeMail to inform the IMC when it moves to a new area, e.g., from the city of Waterloo to the city of Kitchener. Having the location information of vehicles, the IMC is able to provide location-specific ITS services to vehicles by sending emails to vehicle’s mailbox. For example,

- **Road Maintenance Notification:** the road maintenance information of the local area.
- **Traffic Condition Notification:** the timely information of road traffic, especially during the rush hours.
- **Point of Interest:** the information of useful or interesting locations for passengers in the local area.

**Electronic Traffic Ticket:** Once the roadside infrastructure captures a traffic violation and then informs the IMC, the IMC can send an electronic traffic ticket to the vehicle’s mailbox. For example, as shown in Fig. 1, the vehicle is informed its overspeed behavior by the IMC. In such a way, the use of paper-based traffic tickets is not necessary. Moreover, the IMC can also send electronic receipts to vehicles once they receive the toll service in a highway.

**Data Collection:** Vehicles can also regularly send the data collected from the on-board sensors to the IMC by using VeMail. The types of collected data can be location information, vehicle’s physical condition, traffic density, detected accidents, and environmental information (e.g., the concentration of CO\(_2\) in the air), among others. Based on the collected data, the IMC can perform efficient management.

**III. SYSTEM ARCHITECTURE AND DESCRIPTION**

VeMail is responsible for moving messages between vehicles and the IMC, based on most elements of off-the-shelf Internet email systems, e.g., the use of “@” for addressing. The architecture of VeMail system is shown in Fig. 2.

**A. Mail Server**

A vehicle sends or receives email messages by opportunistically accessing its mail server. Logically, the mail server includes a queue of email messages to be sent and the mailboxes of vehicles being served, which contain incoming messages for individual vehicles. Similarly, the management server of the IMC sends or receives email messages by contacting its mail server. The system does not require that the IMC and vehicles use the same email server. The Message Transfer

\(^3\)Emergent safety messages typically require immediate delivery to the recipients [5].

\(^4\)TIME is the acronym of Telecommunications, Information Technology, Media and Entertainment.
Agent (MTA), a software installed on the mail server, is responsible for moving outgoing messages to the recipient’s mail server under Simple Mail Transfer Protocol (SMTP). As per SMTP, email messages are transferred between mail servers by establishing a TCP connection to make sure the transmission is reliable. The format of messages is regulated in the same way as Internet email. The detailed operation of mail transfer can be seen in [7].

B. Mail Client

The mail client is a software installed on the on-board unit (OBU) of vehicles or the management server of the IMC and has two main functions: 1) sending or receiving email messages to or from the corresponding mail server; and 2) showing email messages to users in an appropriate way.

Functionally, the mail client is identified as the Mail User Agent (MUA). One duty of the MUA is to retrieve email messages from the mail server. The message retrieval is regulated by the mail access protocol. The alternatives can be Post Office Protocol (POP) and Internet Mail Access Protocol (IMAP), which are two most prevalent Internet mail retrieval protocols. In addition, the MUA is responsible for transferring messages created by vehicles or the IMC to the corresponding mail server under the regulation of SMTP, and interacting with users for all kinds of mail operations. Since it is required to carefully design the MUA to customize vehicular environments, we put emphasis on the mail client of vehicles and elaborate several important features of the MUA that need to be implemented as well.

- **User Interface**: a user interface is provided by the OBU’s MUA for drivers to write, read, delete, and archive email messages on the panel touch screen.
- **Message Buffer**: since the vehicle may experience intermittent connectivity to its mail server and message cannot be sent during off-line periods, a message buffer is required to temporarily store outgoing messages. Once the connection to the mail server is established, the buffered messages are sent immediately.
- **Voice Support**: when on the move the driver can use the voice support of VeMail system to avoid any distraction. The new message can be automatically notified and read and other voice commands are also implemented for the driver to complete all kinds of mail operations.
- **Programming Interface**: the MUA should offer a programming interface for other softwares running on the

C. Mail Proxy

The mail client of vehicles can establish a connection to the mail server when the Internet access is available. To have access to the Internet, vehicles can communicate with cellular BSs or Wi-Fi APs (V2I communications). Another alternative way to establish a connection between the vehicle and its mail server is through the use of V2R communications. In addition to exchange data with vehicles, the RSU often has connection to the IMC through Internet, such as roadside sensors, which also need to send certain information to the IMC. Therefore, it is possible that the RSU acts as a proxy between vehicles’ mail client and the mail server. As shown in Fig. 3, the OBU is capable of communicating with the RSU due to the equipment of IEEE 802.11p/WAVE interface, while the RSU also has wired or wireless connection to the Internet backbone. In order to fulfill the proxy function, a mail proxy is implemented on the RSU, which can respond to the requests from the mail client by contacting the mail server directly. Fig. 4 shows the procedure of the mail client of vehicles retrieving messages from the mail server through the mail proxy. Upon receiving the WSA_MS (Wave Service Advertisement for Mail Service) message, which is periodically broadcasted by the mail proxy on the control channel (CCH) [8], the mail client of vehicles sends a Mail Retrieval Request to start the process of mail retrieval. The mail proxy obtains the messages from the mail server by establishing a POP or IMAP session, and then sends back the obtained messages to the mail client on one of service channels (SCHs), specified in the Mail Retrieval Response message. An Acknowledgement from the mail client ends the process of mail retrieval if successful.

IV. MAIL RETRIEVAL UNDER INTERMITTENT CONNECTIVITY

Considering intermittent connectivity with RSUs, vehicles on the move may have a short online period every couple of minutes or longer. Nonetheless, it is not necessary for vehicles to retrieve messages during each online period. The reason is threefold: 1) a half an hour or one hour mail retrieval interval is enough in most cases; 2) frequent contact increases the burden of the mail server; and 3) some connection time may be too short to retrieve email messages from the server. Based on

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\footnote{The OBU should include interfaces of V2I communications, which are not shown in Fig. 3.}
the above observations, it is reasonable to develop a scheme to select a long-time connection for retrieving emails during a certain period. To this end, we propose an optimal probabilistic mail retrieval (OPMR) scheme, based on the theory of optimal stopping rules. In this section, we consider that vehicles only needs to retrieval messages from the mail server with the assistance of RSUs.

A. OPMR Scheme

RSUs with the mail proxy function are deployed along the road, where a vehicle can connect and retrieve email messages. The inter-contact time (ICT) is defined as the time duration between contacts for a vehicle and RSUs. The connection time (CT) is defined as the time duration in which the vehicle keeps the connection with the RSU from the beginning of the contact. The ICT and the CT are further modeled to be exponentially distributed with the mean $1/\lambda$ and $1/\mu$, respectively. The rationale of such modeling can be seen in [9]. The system time is divided into time intervals of equal length $T$ ($T \gg 1/\lambda > 1/\mu$), and the vehicle intends to retrieve emails from the server by connecting with the best RSU it observes within each time interval. Let $N_{on}$ denote the number of contacts during a time interval $T$ for a vehicle. Clearly, $N_{on}$ follows a Poisson distribution with the mean $\lambda T$. Assume that once the vehicle is connected to an RSU, it can estimate the CT based on its speed, the signal strength, etc.

In an optimal stopping problem [10], let $Q = (Q_n)_{n\geq 0}$ be a sequence of random variables, observed at time $n$. For each $n$, one can make a decision to stop and receive the known reward $R_n = R(Q_n)$, where $R(Q_n)$ is a function of $Q_n$, or to continue and observe $Q_{n+1}$. However, the past reward cannot be recalled. The optimal stopping problem is to decide when to stop so as to maximize the expected reward. In our problem, $Q_n$ represents the CT of the $n$-th contact within the time interval $T$, and therefore $Q_n \sim \text{Exp}(\lambda)$, $\forall n$. We define $R_n = Q_n \cdot \omega(n)$, where $\omega(n)$ is given by

$$
\omega(n) = \Pr(N_{on} \geq n) = \sum_{i=n}^{\infty} \frac{e^{-\lambda T}(\lambda T)^i}{i!}.
$$

Using $R_n$ as the reward of a vehicle in the $n$-th contact is based on the following considerations. Firstly, during a time interval $T$, the vehicle expects to meet and select an RSU with the longest CT so that it has sufficient time to retrieval all the email messages. On the other hand, if the vehicle keeps waiting one after another, the probability of meeting the next RSU during the remaining time interval $T$ will be reduced. To characterize such a time urgency, the weight $\omega(n)$ is introduced, which is the probability that there are at least $n$ contacts within the time interval $T$. Let $N^*$ be a sufficient large natural number so that $\omega(N^*) = \Pr(N_{on} \geq N^*) < \epsilon$, where $\epsilon$ is an arbitrary small value. We consider the mail retrieval as an optimal stopping problem with a finite horizon $N^*$. Let $V_n$, $n \in \{1, 2, \ldots, N^*\}$, denote the maximum expected reward the vehicle can achieve starting from the $n$-th contact, which is given by $V_n = \max\{R_n, E[V_{n+1}]\}$, $\forall n \in \{1, 2, \ldots, N^*-1\}$, and $V_{N^*} = R_{N^*}$, for $n = N^*$. The optimal stopping of mail retrieval is that the vehicle will decide to retrieval emails in the current $(n$-th) contact with RSUs as long as $R_n \geq E[V_{n+1}]$.

In the following, we use backward induction [11] to derive $E[V(n)]$, $\forall n \in \{1, 2, \ldots, N^*\}$, so as to obtain the set of optimal retrieval rules. As per the definition,

$$
E[V_n] = E[\max\{R_n, E[V_{n+1}]\}]
= \int_0^\infty \max\{Q_n \cdot \omega(n), E[V_{n+1}]\}dF_{Q_n}(q)
= \int_0^{E[V_{n+1}]} E[V_{n+1}]dF_{Q_n}(q)
+ \omega(n) \int_{E[V_{n+1}]}^{\infty} qdF_{Q_n}(q)
= E[V_{n+1}](1 - e^{-\mu E[V_{n+1}]})
+ \omega(n)(E[V_{n+1}] + 1/\mu)e^{-\mu E[V_{n+1}]},
$$

where $F_{Q_n}(q) = 1 - e^{-\mu q}$ is the cumulative distribution function (CDF) of $Q_n$. Knowing the set of optimal retrieval rules, vehicles can accordingly choose an optimal RSU for mail retrieval within each time interval $T$. Algorithm 1 shows the OPMR for vehicles.

B. Performance Evaluation

![Fig. 4. Mail retrieval through the use of mail proxy.](image-url)
We use simulation to evaluate the performance of the proposed OPMR scheme and compare it with the regular mail retrieval method, i.e., the vehicle retrieves emails during the first online period in every time interval \( T \). We denote by CTR the CT of the contact during which the vehicle connects to the mail server to retrieve emails. Fig. 5 shows the CTR with respect to (w.r.t.) \( \lambda T \) with \( 1/\mu = 5 \) seconds. Recall that \( \lambda T \) is the mean of \( N_{on} \) which is Poisson distributed. For the regular retrieval method, it can be seen that the average CTR remains 5 seconds since the first online period theoretically follows exponential distribution with the mean \( 1/\mu \). The OPMR scheme offers better CTRs due to the optimal selection of the retrieval contact. For example, when \( \lambda T = 20 \), the CT that can be used for mail retrieval is around 16 seconds. The CTR increases with \( \lambda T \). That is, a large value of \( N_{on} \) typically yields a large value of CTR. Similarly, better performance of the proposed method can be seen in Fig. 6 which shows the CTR w.r.t. \( \lambda T = 10 \). The average CTR increases with \( \mu \) with a fixed value of \( \lambda T \). It is possible that the vehicle keeps waiting for the optimal contact with RSUs so that it fails to retrieve emails within \( T \) by using the OPMR scheme. Therefore, we evaluate the intervals between successive retrievals for both the proposed scheme and the regular retrieval method, as shown in Fig. 7. It is set that \( 1/\mu = 5 \) seconds and seen that for the OPMR scheme the retrieval interval is typically greater than \( T \), which demonstrates that a strict retrieval interval is difficult to attain for opportunistic message retrieval method. On the other hand, it is not necessary to require a strict retrieval interval for vehicular environments. We can see that the average retrieval interval gradually approach \( T \) with the increase of \( \lambda T \). When \( \lambda T = 30 \), the average retrieval interval is almost \( T \) with an average CTR of 18 seconds.

V. RELATED WORK

Although Internet email is a mature application, the effort of building email applications for ITS is very limited. In [12], Ueda et al. proposed an email system for the wearable computing environment, wearable devices being typically connected with the network all of the times, which is different from the vehicular environment where vehicles may experience intermittent connectivity. Applying the optimal stopping approach for forwarder selection in delay tolerant networks (DTNs) can be seen in [11], which is proposed to calculate the forwarding probabilities of each node.

VI. CONCLUSION

In this paper, we have described an electronic mail system for ITS, which is called VeMail, by means of V2R and V2I communications. As a basis of messaging for ITS, the VeMail system which is composed of mail server, mail client, and mail proxy, can support a variety of emerging ITS applications. Since the always-on connection of vehicles to the mail server may not be achievable, we have proposed an optimal probabilistic message retrieval (OPMR) scheme under intermittent connectivity. Simulation results have demonstrated that the proposed scheme outperforms the regular mail retrieval method in terms of the connection time with the mail server.

REFERENCES