On the Feasibility of Using Public Transport as Data Mules for Traffic Monitoring

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Abstract—A broad range of diverse technologies, known collectively as intelligent transportation systems (ITS), holds the answer to many of our transportation problems. ITS provides the intelligent link between travellers, vehicles, and infrastructure. In this paper, we study the feasibility of an architecture that involves deploying mobile gateways on a selected subset of public transport vehicles for one particular ITS application: traffic monitoring. We assume that all buses, bus stops and traffic lights are equipped with a wireless device to communicate with in-range neighbours (e.g. other buses). In our analysis, we use realistic movement patterns of public transport buses in a metropolitan city. Our results suggest that it is feasible to use such an architecture with existing radio technologies for traffic monitoring applications.

I. INTRODUCTION

With the increasing popularity of Intelligent Transport System (ITS) around the world, the future of ITS is promising. The use of ITS in Japan, Europe, Australia and US has been greatly accelerated recently through mutual cooperation of the public and private sectors. A projected 209 billion will be invested in ITS between now and the year 2011 – with 80% of that investment coming from the private sector in the form of consumer products and services [1]. Recently a new paradigm of Networks in Motion is quickly attracting interest from the research community and is also being viewed as a viable commercial solution [2], [3], [4]. A typical on-board network, as illustrated in Figure 1, consists of an on-board LAN (wired and/or wireless), which is connected to the Internet through a mobile gateway. Such a mobile gateway can utilize a diverse array of wireless access technologies (e.g: GPRS, UMTS, 802.11) through multiple service providers. In this work, we propose an architecture in which a small number of mobile gateways are deployed on a few selected buses. In addition, we assume that each bus is equipped with a wireless device which allows it to communicate with buses within its radio range and form a self-organized ad-hoc network cluster. While travelling along their regular routes, the buses dynamically join and leave clusters.

In this paper, our goal is to evaluate the feasibility of such an architecture, for which we use real-world mobility traces collected from the bus system of a metropolitan city. We want to address the following questions:

• Given that the size of cluster is strongly affected by the radio range of each bus, which existing radio technology might be feasible for such an architecture?
• How many mobile gateways need to be deployed for providing an acceptable performance?

The ideas of using mobile gateways are not new. Our contribution lies in a quantitative evaluation for vehicular scenarios using real-world traces. In addition, to simplify our analysis, we assume that the radio has a circular range and has perfect coverage in that range. While this might ignore the effects of multi-path and fading, our results are still useful as a first step to understand the feasibility of using public transport for ITS applications.

The rest of this paper is organized as follows. In Section II, we briefly discuss related work. In Section III, we study the feasibility of using public transport as data mules for traffic monitoring in urban areas. Finally, we present concluding remarks in Section IV.

II. RELATED WORK

Several researchers have previously studied the feasibility of using moving vehicles to form a network backbone. This section provides a discussion with

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regards to the architecture and methodology employed therein.

Namboodiri et al., [5] studied the feasibility of placing mobile gateways on selected vehicles to provide connectivity to the other vehicles in their vicinity. Their proposed architecture is similar to ours but there are several differences. Firstly, their simulations were conducted for a highway scenario wherein the nodes and mobile gateways were uniformly distributed along a straight long highway. Moreover, they assume a first-order Markov model to characterize the motion of the vehicles. In our work, we are using realistic movement traces of buses within a metropolitan city.

Huang et al. [6] proposed an application scenario for mobile ad hoc networks in the form of a radio dispatch system for taxis and investigate its financial and technical feasibility. In their evaluations they modeled the city as a grid [7] of size 5 km x 5 km, with 300 taxis distributed within this area. They evaluated the effect of parameters such as node density and congestion on the coverage and outages experienced and concluded that their system does perform satisfactorily under most operating conditions. Their focus was however on studying the performance of an application on a purely ad hoc network, which is different from the architecture that we aim to evaluate in this study.

Ad Hoc City [8] present a multi-tier architecture for providing Internet connectivity to mobile users. In their architecture, several fixed Internet connected static base stations are deployed throughout the city. A multi-hop network composed of wireless devices mounted on mobile vehicles such as cars and buses forms the backbone, and the vehicles connecting to the static gateways as they move through the city. Individual users can utilize the mobile backbone to access the Internet, with the backbone relaying the user packets to the static gateways, either directly or using multi-hop routing. Similar architectures have also been discussed in [9], [10], wherein vehicles connect to the Internet as they drive-by static gateways, which are periodically deployed along the highways. Unlike their scheme, our architecture does not focus on the use of static gateways.

Kaixin et al. [20] proposed a hierarchical ad hoc network architecture in which each hierarchy has a different radio capability. In this design, the mobile gateway has a higher-powered radio and forms the network backbone. Each mobile gateway services a cluster of mobile nodes. Mobile gateways are deployed in numbers greater than required, so that the redundant gateways can take over the role of a defunct gateway. When a gateway dies, a new gateway is automatically elected by the nodes in a cluster. In their study the mobile gateways move randomly while our nodes exhibit predictable mobility.

Arnab et al. [18] used public transport as a mobile sink for sensor networks. They made use of single-hop and multi-hop sensor networks to send sensor data to the mobile data mule. They had a similar objective to ours in terms of finding the performance of a data mule system. But their study only considered one sensor network, while we considered multiple sensor networks. In addition, they only looked at the effects of single data mule while we consider multiple data mules moving around sensor networks. Ioannis et al. [19] proposed and investigated the use of mobile sinks for sensor data dissemination. However, they used simple movement patterns such as a straight line or a circle for their predictable mobility study, while we made use of realistic mobility patterns of a large number of buses.

III. USING PUBLIC TRANSPORT AS DATA MULES FOR TRAFFIC MONITORING

In this paper, we investigate the feasibility of using public transport of a metropolitan city as data mules to collect traffic sensor data. In this scenario, we assume that traffic sensors are deployed on all urban roads for applications such as vehicle counting and detection. Traffic sensor data can be collected by public buses and then uploaded to the traffic management centre via some static or mobile gateways. Majority of the buses act as data mules which route sensor data to a gateway, while a selected subset of buses act as mobile gateways to send sensor data to the Internet. In addition, all traffic lights are considered as static gateways. We evaluate the characteristics of such an architecture, consisting of a mixture of data mules, mobile gateways and static gateways, built on top of the public transport system.
Note that we assume that all buses, bus stops and traffic lights are equipped with a wireless device to communicate with in-range neighbours, which in turn forms ad hoc network clusters among themselves.

We decided to use another set of traces for this study since the evaluation of such a system requires location information of bus stops and traffic lights. We utilize the bus timetable information from the Sydney Buses Transport Infoline [16] website for our study. The bus timetables we use cover Sydney’s eastern suburbs, which have an area of 400sq km and being serviced by 4813 buses in 57 routes. GPS coordinates of the bus stops involved are collected using Google Earth, by manually marking the location of bus stops on Google Earth and then processing its output KML files [24]. As the bus stops are named like ‘Anzac Pde Nr Gardeners Rd’ the locations of the stops are obtained by referencing the name of the stop with road information obtained from whereis.com [21] website and subsequently entered into Google Earth. We obtained coordinates of traffic lights from Road and Transport Authority of New South Wales. All traffic lights are considered as static gateways due to the built-in networking abilities of traffic light systems in Sydney. Majority of the traffic lights in Sydney are linked to the Sydney Coordinated Adaptive Traffic System (SCATS) [17] which already has the networking infrastructure to make use of, hence making it a desirable choice for deployment as gateways.

A. Methodology

In this section, we first discuss some assumptions we made. We then present how we analyze the data.

1) Assumptions: In this study, we have made several assumptions due to the constraints given by the bus timetable data, namely:

- When a bus is travelling from one bus stop to another, it travels in a straight line. This is due to that the timetables only have location information of a bus at the bus stop.
- All wireless nodes have LOS to their neighbours (e.g. 100m radio range for 802.11). This is due to our limited geographical knowledge regarding surroundings of bus routes.
- We assume that the traffic sensor is co-located with bus-stop. Therefore, the bus can collect sensor information while picking up its passengers.

2) Metrics:

a) Cluster Size: The ad-hoc network that is formed amongst the buses is typically made up of several partitioned network clusters at any given time. The composition of the clusters changes dynamically over time. The cluster size is defined as the number of buses in each cluster.

b) Mobile Gateway Selection: Intuitively, a bus that encountered a higher percentage of other buses along its route is a better candidate for the mobile gateway. Therefore, we select the mobile gateway among buses based on the following criteria:

- The candidate is chosen from a frequently serviced route.
- The candidate’s route should intersect with a high percentage of other buses’ routes.

Based on the above criteria, the top 25% routes are chosen. We also look at the effect of having different numbers of mobile gateways on the performance of the network, which is described in Section III-B.

B. Results

In this study, we consider two different radio ranges: 100m and 1000m which correspond to the coverage provided by 802.11 and DSRC. Figure 2 shows that 95% of the distance between fixed nodes falls within 1km, while only 20% of them are less than 100m. This
seems to suggest that it is possible to form a wireless backbone with the fixed nodes using DSRC.

The inter-arrival time of buses at each bus stop indicates how frequent data from sensors located at bus stops can be picked up by the buses and determines how often traffic information can be updated. It is desirable to have this metric as low as possible to allow for frequent updates of sensor data. However, given that the arrival time of buses at the bus stop is closely related to their departure interval from the bus depot, it is difficult to have very frequent update of traffic sensor data. In our dataset, most of the buses depart from their depot at fixed intervals. 90% of buses have departure interval less than 30 minutes. Figure 3 shows 80% of bus stop have a bus inter-arrival time of less than 7 minutes.

Next we consider how long it takes for a bus to drop the sensor data at the static gateway after it picks up the traffic information at the bus stop. Figure 4 shows the travel time of a bus between two traffic lights. We find that most of the time (80%) the sensor can be dropped at a static gateway in less than 3 minutes, although occasionally the delay can be up to 7 minutes.

Figure 5 shows the number of clusters formed during a day, averaged to number of clusters per minute. There are more clusters between at 8am and 5pm (there are very few buses servicing outside this period). In addition, there is an increase in the number of clusters during peak hours (e.g. around 8am and 5pm) because more routes are serviced at that times. Surprisingly, the radio range does not have a significant effect on the number of cluster. This is due to a large number of ‘orphan clusters’ in our data. In addition, the inter-node distances within a cluster are typically short (less than 100m) while the inter-cluster distance are typically long (longer than 1000m). Figure 6 shows the distribution of cluster size at 8am. We find that almost 60% of the clusters are orphaned clusters (defined as the cluster which has only one bus) at 8am. As a result, increasing the radio range does not have an effect on the cluster size because these orphan buses are typically far away from any other buses.

Finally, we look at the effects of the number of mobile gateways on the network performance. As expected, an increasing number of gateways increases the amount of buses covered. As shown in Figure 7, to achieve 80% of coverage, we need 25% of total buses to serve as mobile gateways. Note that the difference in radio range does not seem to have a significant effect.

Fig. 4. CDF of travel time between traffic lights

Fig. 5. Average number of clusters formed during a day

Fig. 6. CDF of cluster size at 8am

Fig. 7. Percentages of buses covered by mobile gateways
Fig. 8. Average latency for sensor data to reach mobile gateways

on the percentages of buses covered. Our hypothesis is that, although we have increased the number of mobile gateways, there are still a significant number of orphaned clusters as shown in Figure 6. An increase in radio range does not necessarily facilitate lesser orphans in the network as the buses can be still out of range with each other.

Figure 8 shows the delay from when sensor data was collected to the time the bus encounters a mobile gateway. On average, the sensor data can be uploaded to a mobile gateway 2.5 minutes with 10% of buses are deployed as mobile gateways, which is considerably better than the use of static gateway. As shown in Figure 4, 40% of the time a bus needs to travel longer than 2 minutes to reach a static gateway. Again, a longer radio range does not improve the latency to reach a mobile gateway.

IV. CONCLUSIONS AND FUTURE WORK

In this paper, we study the feasibility of providing ITS services using an ad-hoc architecture built on top of public transport systems, where packets are routed to the Internet via mobile gateways. For our evaluations, we use realistic mobility patterns of city buses from a metropolitan city. We also analyze the influence of the radio ranges on our results. Based on our analysis, we conclude that DSRC with a range of 1 km is a reasonable candidate for our scenarios. By optimally choosing the candidate buses as the gateways, at least 80% of the buses can be covered with the deployment of 20% of the overall buses to serve as mobile gateway.

Due to the limitation of our traces, we are only able to obtain statistics at the order of minute. An important next step would be to repeat the above analysis for other traces and obtain a set of generalized results. Moreover, the statistical results in this paper are all empirical distributions (i.e. CDFs). A future extension could involve developing analytical models from them so that one can get a better insight into their statistical properties (such as that if some metrics are heavy-tailed).

REFERENCES

[17] SCATS Booklet, 31 Oct. 06
