

# Feasibility Study of Using Mobile Gateways in Public Transportation Vehicles for ITS Applications

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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 two ITS applications: providing Internet connectivity to the passengers and 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 ITS 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 more feasible for such an architecture?
- How many mobile gateways need to be deployed for providing an acceptable performance? In particular, we study the application of such an architecture for two ITS applications: providing Internet connectivity to on-board users (Section III) and traffic monitoring (Section IV). The ideas of using mobile gateways are not new. Our contribution lies in a quantitative evaluation for vehicular scenarios using real-world traces.

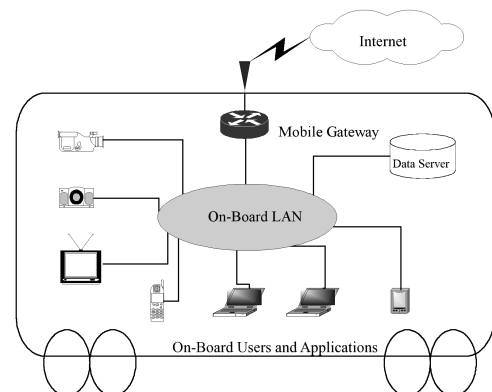


Fig. 1. A typical on-board network that uses a mobile gateway to connect to Internet

The rest of this paper is organized as follows. In Section II, we briefly discuss related work. Section III presents an analysis of using mobile gateways to provide Internet connectivity in public transportation vehicles. In Section IV, we study the feasibility of using public transport as data mules for traffic monitoring in urban areas. Finally, we present concluding

remarks in Section V.

## 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 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. PROVIDING INTERNET CONNECTIVITY IN PUBLIC TRANSPORTATION VEHICLES

The extension of Internet services to public transport passengers is slowly becoming inevitable. Several architectures for providing Internet access to moving vehicles have been evaluated in the past [4]. However, most of these studies focused on using static gateways. In this section, we study the feasibility of an architecture that involves deploying mobile gateways on a selected subset of public transport vehicles for providing Internet connectivity to the entire fleet. Note that in this paper we only consider the network connectivity graph among buses. Other factors, such as available link bandwidth, could also have an effect on providing Internet connectivity on buses.

The mobility model used in this study is based on the actual movement of buses in the King County Metro bus system in Seattle, Washington [8]. The King County bus system is composed of over 1440 buses covering a 5100 square kilometer area. The format of traces consists of time, bus id, route id and bus location. The traces capture the bus activities from 8 September 2001 to 9 September 2001. The buses have a highly predictable day-to-day pattern. Here, we first examine some characteristics of bus movement patterns which are independent of system parameters such as the placement of the gateways and the communication range of the wireless devices. Figure 2 shows that about 90% of the buses have a speed of less than 40 km/h. Since the speed is highly correlated to the degree of mobility, knowledge of bus speeds can be used to predict several important parameters, such as the duration for which routing paths to the mobile gateways will be active, the neighbor list at any node, etc.

Figure 3 shows the CDF for the distance between neighboring buses. This proves useful for estimating the required radio range and subsequently the wireless technology for inter-bus communication. Figure 3 indicates that 65% of the buses are less than 1 km away from their nearest neighbor. This suggests that a radio range of 1 km is a judicious choice. Coincidentally, the communication range for the DSRC (Dedicated Short Range Communications) [11] standard is also 1 km.

### A. Metrics for Evaluating Coverage

In this section we present the metrics that we use to characterize the connectivity of the buses. Note that, our goal here is to evaluate the extent of coverage possible by deploying mobile gateways on a subset of the entire buses. We are

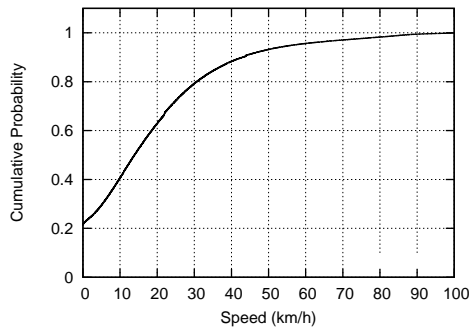


Fig. 2. CDF of bus speeds

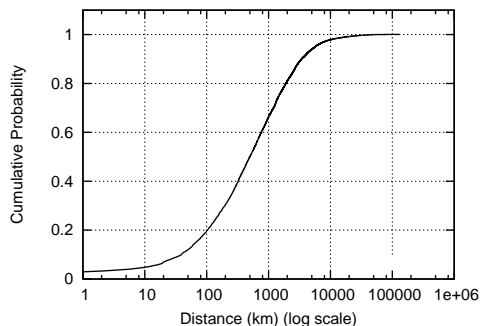


Fig. 3. CDF of inter-neighbor distance

mainly interested in evaluating the reachability at the physical layer independent of the routing protocol in use. Naturally, these characteristics are dependent on the radio range of the wireless devices on each bus. We can broadly classify these metrics into two groups. The first group of metrics (1-4) are used to gain an understanding of the effect of the mobility on various aspects of the inter-bus connectivity such as the link duration and path duration. The second group of metrics (5-6) assume that a certain number of mobile gateways have been deployed on optimally chosen buses, the procedure for which is described below. These metrics then study various aspects of the resulting connectivity that is observed in the network. All of these metrics can provide insights into the expected performance that different applications may perceive once deployed in such a system. Note that in the rest of the paper we will frequently refer to the buses as nodes and the buses equipped with mobile gateways as simply gateways.

1) *Cluster Size and Number of Clusters*: The ad-hoc network that is formed amongst the buses is typically made up of several partitioned network clusters at any given time. Further, the composition of the clusters keeps changing dynamically over time. The cluster size measures the number of buses that constitute each cluster. All nodes within a cluster can reach each of the other nodes via either a single-hop or multi-hop path. Hence, provided the size of a cluster is not very large, it may be sufficient to deploy one gateway for each cluster to ensure basic connectivity to all nodes. For large clusters, it may be necessary to deploy multiple gateways to reduce contention within the cluster. A general rule of thumb suggests that the number of mobile gateways needed would be at least equal to the number of clusters being formed.

It is also important to get a sense of the number of *orphan*

*clusters*, i.e, the clusters that only have one member. This is because ensuring connectivity to all orphans would warrant installing a gateway atop each of the orphans. Hence, a larger percentage of orphan clusters would potentially require the deployment of a larger number of mobile gateways.

2) *Link Duration*: This metric indicates the average time that a pair of buses are within each others' radio range. In other words, it shows how long two buses can communicate with each other directly. Since buses are dynamically moving, the links are prone to be broken frequently.

3) *Path Duration*: Path duration refers to the time that one bus can reach another bus and is used to illustrate how long, on average, a path can be maintained. The difference between a path and a link is that a path can be established via either single or multiple hops while a link refers to single-hop communication.

4) *Longest Path*: The longest path denotes the topological distance between two farthest nodes within the same cluster. It gives a sense of the physical dimension of the clusters.

5) *Percentage of Buses Covered*: One would have to deploy at least one mobile gateway in each cluster to provide Internet connectivity to the entire cluster. Note that for very large clusters, multiple gateways would be desired, particularly if the bandwidth required by each node is high. However, in this study we are primarily concerned with providing basic connectivity and hence do not address this issue further. This metric shows the average percentage of nodes that can connect to the Internet, given that a certain number of gateways have been deployed.

Clearly, the choice of the buses on which the mobile gateways are deployed will affect this metric. The buses that are always part of large clusters are ideal gateway candidates. In our evaluations, we have analyzed the clustering patterns of the buses and have devised an optimal gateway placement policy. We first rank the buses according to the average percentage of other nodes that they can provide connectivity to over the entire trace duration. In order to place  $n$  gateways in an optimal manner, our algorithm cycles through all  $n$  possible combinations from amongst the high ranking nodes to determine the combination that can provide the maximum coverage. Our optimal placement algorithm is particularly feasible for public transport systems, given that the buses always run along fixed routes according to set timetables. The pseudo-codes of our optimal gateway placement algorithm are shown below.

```

FOR i = 0 to totalNumOfBuses - 1
  maxCoverage = 0
  FOR each bus NOT found in SelectedBusForGateway
    SelectedBusForGateway[i] = bus
    value = % of coverage of SelectedBusForGateway
    IF maxCoverage < value THEN
      maxCoverage = value
      nextBus = bus
    ENDIF
  ENDFOR
  SelectedBusForGateway[i] = nextBus
ENDFOR

```

6) *Gateway Path Duration*: This metric measures the duration for which an unbroken path exists between a node and a gateway. The average is computed over all paths that existed at least once between a node and a gateway. We use the same

optimal gateway placement policy as described above. This metric has a direct implication on the target applications since frequent expiration of the paths will lead to highly intermittent connectivity. However, it can be argued that path breakage may not affect applications if a new one can be found soon enough [8].

## B. Evaluation

In this section we present the results of our analysis of bus traces. Again, our goal here is to evaluate the characteristics of the network connectivity at the physical layer, independent of routing. We also seek to investigate the effect of the radio range on the observed characteristics and hence choose three different ranges: 100m, 1 km and 15 km which correspond to the coverage provided by three candidate access technologies: 802.11, DSRC and 802.16 [12], respectively.

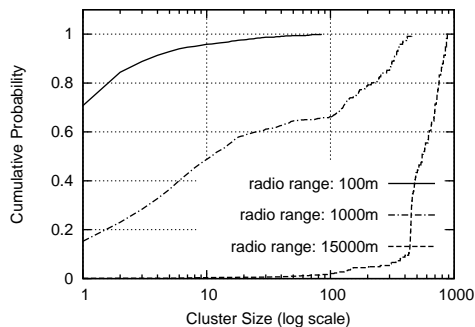


Fig. 4. CDF of average cluster size

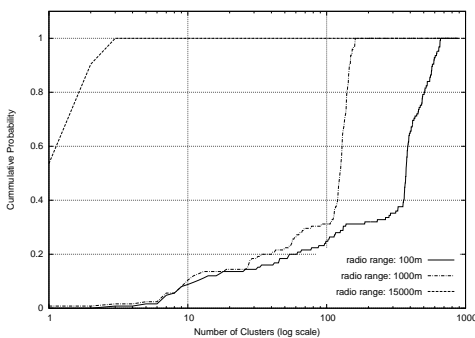


Fig. 5. CDF of average number of clusters

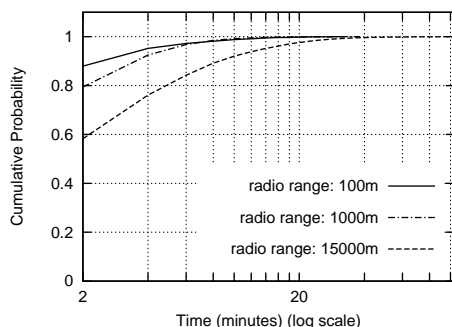


Fig. 6. CDF of average link duration

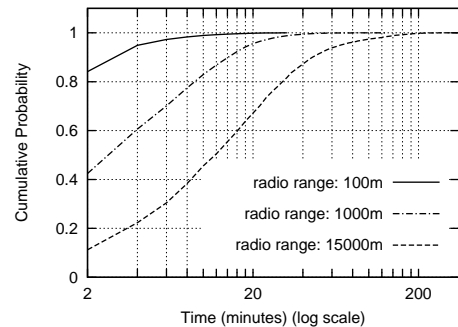


Fig. 7. CDF of average path duration

1) *Cluster Size and Number of Clusters*: Figure 4 shows the CDF for the average cluster size. As seen from the graph, for the 100m radio range, 70% of the buses form orphan clusters and there are only 2 buses in each cluster, on an average. On the other hand, with 1 km, the percentage of orphan clusters significantly reduced to around 15%. Furthermore, there is a significant percentage of clusters with approximately 100 to 400 bus members. These large clusters possibly are formed around city district area at peak times. Overall, the average cluster size is 8 nodes. For the 15 km radio range, as expected, there are no orphan clusters and the cluster size increases dramatically. The ad hoc network is almost always partitioned into 2 or 3 mammoth clusters, with an average of 334 buses per cluster.

2) *Link Duration*: Figure 6 shows the distribution of the one-hop link durations for different radio ranges. As observed, most of the one-hop links are active for less than 2 minutes. The probability that the link duration is longer than 2 minutes is approximately 13%, 20% and 40% for the 100m, 1km and 15km radio ranges respectively. In general, the link duration increases as the radio range increases. However, the introduction of a longer radio range does not significantly affect the link duration.

3) *Path Duration*: The CDFs for the path duration are illustrated in Figure 7. Path duration is always equal to or greater than the link duration since it also accounts for multi-hop paths. For the 100m radio range, approximately 15% of buses have a path duration greater than 2 minutes. However, the path duration increases significantly for the 1km range. The result shows that there is almost a 60% chance that 2 nodes can maintain a path for more than 2 minutes. Finally, as expected, with 15 km the paths remain stable for an even longer duration of time.

4) *Longest Path*: Figure 8 shows the average length of the longest path for different cluster sizes for each of the radio ranges under consideration. In the cases of the 100m and 1km radio ranges, we observe that the longest path increases gradually with the cluster size. In addition, the observed longest path is significantly smaller in comparison to the longest path that can be formed amongst the nodes. For example, if 10 nodes are positioned in a chain topology along a straight line, and if the radio range is 100m, then the maximum possible path length is 1000m. However, Figure 8(a) suggests that on average the longest path for a cluster of size 10 is only around 300m. Figure 8(a) and 8(b) suggests that

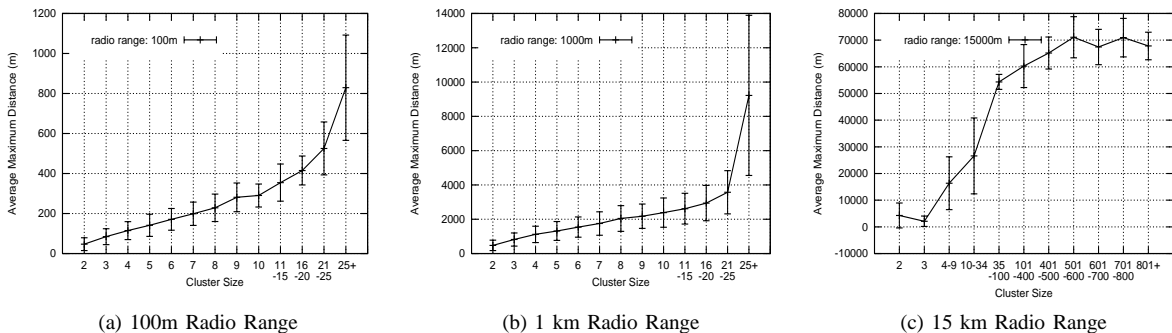


Fig. 8. CDF of the longest path

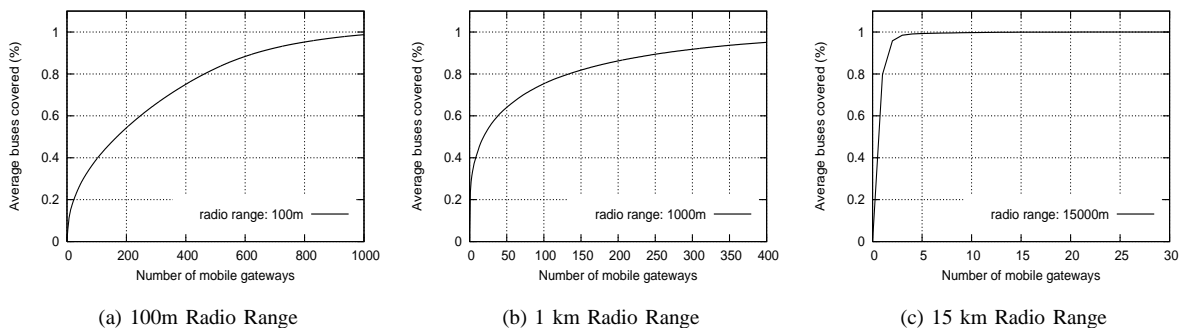


Fig. 9. Percentage of buses covered as a function of the number of gateways

this difference is even greater for larger clusters, due to the fact that a large number of the buses are clustered quite close to each other. For the radio range of 15km, most clusters have more than 400 members as shown in Figure 4. As seen from Figure 8(c) the average recorded longest path is 70 km across all cluster sizes. Note that, intuitively the longest path in a cluster should increase as the cluster size increase, as in the cases of 100m and 1km radio ranges. However, this is not always true for the 15km radio range. This is because, as observed from Figure 6, there are many buses with an inter-bus distance of much less than 15 km. Thus, the longest path does not necessarily increase with the cluster size.

5) *Percentage of Buses Covered*: Figure 9 illustrates the percentage of buses covered as a function of the number of gateways for different radio ranges. We use the optimal gateway placement algorithm as described in Section III-A.5 for placing the mobile gateways. As expected for the long range of 15km, only a handful of gateways, 5 to be precise, are sufficient to cover all buses. For the other two radio ranges we observe a gradual increase in the percentage of coverage with an increase in the number of gateways. For example, to achieve 80% coverage we need 470 and 150 gateways for the 100m and 1km radio ranges, respectively. However, for complete coverage the gateways needed increase to 1000 and 800 for these two cases.

6) *Gateway Path Duration*: Path duration refers to how long, once a node connects to a gateway, the connectivity can be maintained (via either single or multiple hops). Figure 10 indicates that the average duration of a path from a node to

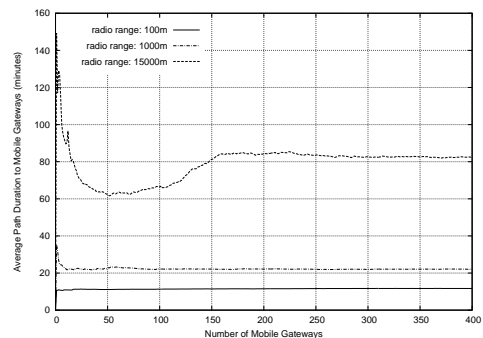


Fig. 10. Average gateway path duration

a gateway is independent of the number of gateways and is fairly constant. The results are promising for non-real time applications such as web browsing and e-mail which do not require connectivity for a long stretch of time. If a new path to the mobile gateway can be found soon enough following a disconnection, these applications would function in an uninterrupted manner.

#### IV. USING PUBLIC TRANSPORT AS DATA MULES FOR TRAFFIC MONITORING

Our second case study is to 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

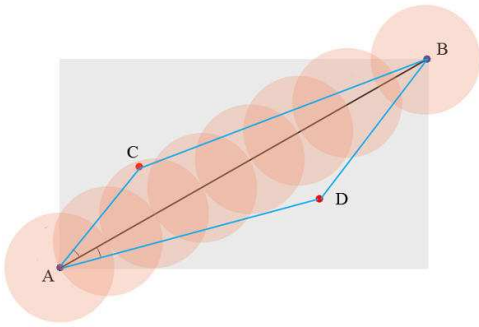


Fig. 11. Intermediate fixed nodes when the bus travel from A to B

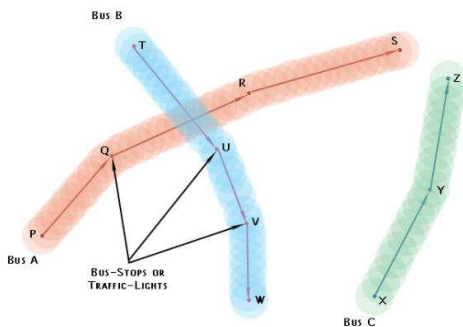


Fig. 12. The radio-boxes when buses move along their paths

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) *Data Preparation:* Due to constraints of our data, it is not possible to get exact information on what fixed nodes the bus passes by and what other buses it encounters during its daily route. We developed some algorithms to determine the fixed nodes and neighbours in our analysis.

a) *Determine the fixed nodes along the bus route:* Since only bus-stops are known from the timetable, missing nodes along a bus route have to be filled in to get an idea of the possible fixed nodes a bus passes by. These fixed nodes can either be a bus-stop or a traffic-light. Fig. 11 illustrates an example how we determine the fixed nodes along the bus route. We first look at the coordinates of two consecutive bus stops in the bus timetable (point A and B) and tries to obtain a list of other nodes that falls between A and B. In this example, C and D are obtained (however, only C is within the radio range of the bus). C and D are then sorted by the distance from A. Finally, basic trigonometry is used to find out whether C and D will be in radio range of the bus.

b) *Finding Bus's Neighbours:* A bus is considered as a neighbour of another bus when its *radio-box* intersects another bus's *radiobox*. As shown in Figure 12, a radio-box is formed when the bus moves along its path, numerous radio circles intersecting each other which eventually formed a rectangle box. Figure 12 shows bus A's path intersecting with bus B, while bus C does not cross bus A's or B's path. In this example, bus B is considered as a neighbour of bus A at segment QR of bus A's route. Bus A is considered as a neighbour of bus B at segment TU of bus B's route. We recursively search for a bus's neighbours at each segment, and look for the optimal path a packet can take while the bus is in motion. The route which has the shortest latency is considered as the optimal path (the path with a shortest hop-count is used when there is a tie).

3) *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 IV-B.

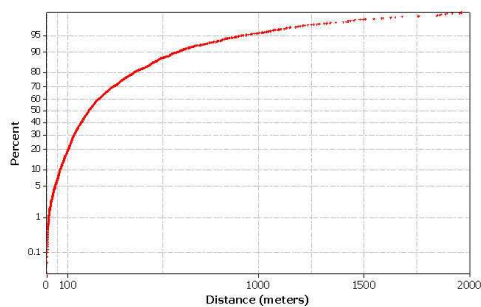


Fig. 13. Probability distribution of distance between fixed nodes

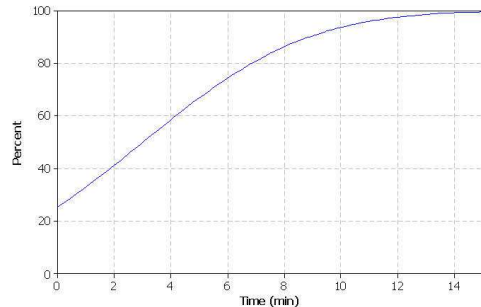


Fig. 14. CDF of bus inter-arrival time at bus stops

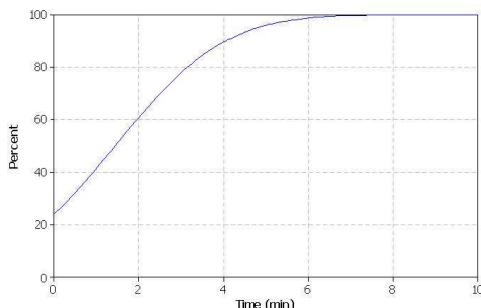


Fig. 15. CDF of travel time between traffic lights

## 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 13 shows that 95% of the distance

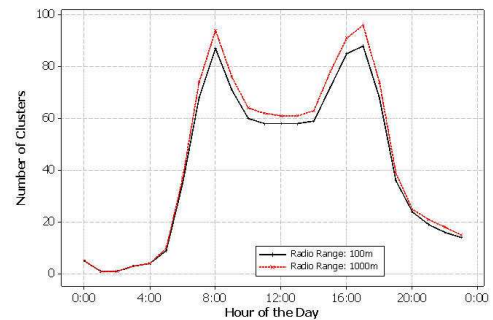


Fig. 16. Average number of clusters formed during a day

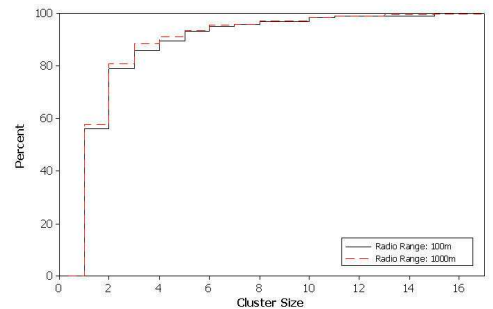


Fig. 17. CDF of cluster size at 8am

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 14 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 15 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 16 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 17 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.

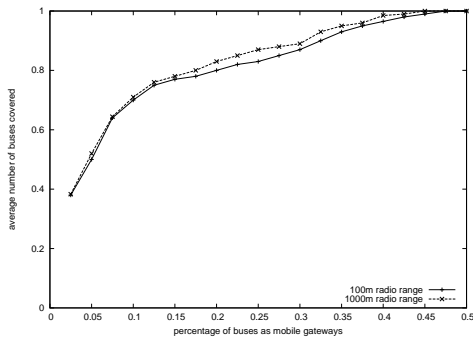


Fig. 18. Percentages of buses covered by mobile gateways

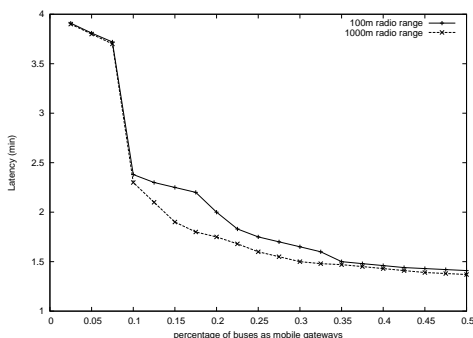


Fig. 19. Average latency for sensor data to reach mobile gateways

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 18, 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 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 17. 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 19 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 15, 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.

## V. 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 an ideal candidate for our scenarios. With DSRC, the percentage of orphan clusters is less than 20% and most clusters are reasonably small, implying that deploying one gateway per cluster would result in reasonable per-node throughput. 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. For both of the datasets we used, we observed that there are significant number of orphaned clusters at certain times, which suggests that a lot of buses are not within radio range of each other, most likely due to their routes.

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). Finally, we have made some assumption about the radio's capabilities for our analysis. A wireless survey in the 'concrete jungle' will be helpful in producing more accurate results.

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