# MOBILITY 2018

The Eighth International Conference on Mobile Services, Resources, and Users

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**MOBILITY 2018 Editors**

Subhasish Mazumdar, New Mexico Tech, USA

# MOBILITY 2018

# Foreword

The Eighth International Conference on Mobile Services, Resources, and Users (MOBILITY 2018), held between July 22 - 26, 2018- Barcelona, Spain, continued a series of events dedicated to mobility-at-large, dealing with challenges raised by mobile services and applications considering user, device and service mobility.

Users increasingly rely on devices in different mobile scenarios and situations. "Everything is mobile", and mobility is now ubiquitous. Services are supported in mobile environments, through smart devices and enabling software. While there are well known mobile services, the extension to mobile communities and on-demand mobility requires appropriate mobile radios, middleware and interfacing. Mobility management becomes more complex, but is essential for every business. Mobile wireless communications, including vehicular technologies bring new requirements for ad hoc networking, topology control and interface standardization.

We take here the opportunity to warmly thank all the members of the MOBILITY 2018 Technical Program Committee, as well as the numerous reviewers. The creation of such a broad and high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to MOBILITY 2018. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the MOBILITY 2018 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that MOBILITY 2018 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the areas of mobile services, resources and users.

We are convinced that the participants found the event useful and communications very open. We hope that Barcelona provided a pleasant environment during the conference and everyone saved some time to enjoy the charm of the city.

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# Drivers' Activities in Cars during Serious Traffic Congestion

## Toward the Development of ICTs for Enjoying Traffic Congestion

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***Abstract*— One possible way of reducing drivers' psychological burden under severe traffic congestion is to reframe their travel time as "valuable time" via "Information and Communication Technologies (ICTs) for enjoying traffic congestion." Such technology, of course, must be safe for drivers and satisfy legal restrictions. As a first step, a questionnaire survey was conducted to grasp drivers' activities during traffic congestion, thus clarifying the possible content of these ICTs, as well as the target groups. Overall, the majority of participants reported engaging in conversations to pass the time when they had passengers in the car. Furthermore, for long-term congestions, these drivers selected more active activities (i.e., activities requiring specific motions to be performed). Drivers without any passengers tended to select passive activities (i.e., activities that do not require specific motions) during short-term traffic congestions. Younger drivers and more creative and curious drivers also selected active activities during long-term congestions. Taken together, the results suggest that one of our future main targets for these ICTs is young people with passengers (particularly for long-term traffic congestions).**

***Keywords–driver's activities; mobile application; ICT; traffic congestion; novel concept.***

## I. INTRODUCTION

In this study, we introduce a new idea for coping with traffic congestion. In the following sections, we relate past work in this area and then provide an outline of the present study.

### *A. A new idea for coping with traffic congestion*

In many countries, traffic congestion is a serious problem that lacks an effective solution. In large cities, the main reason for traffic congestion is usually rapid motorization in conjunction with slow road infrastructure construction. However, severe congestions also commonly occur in relatively small cities, especially after events or festivals that generate a large, unusual traffic demand. Resolving these problems requires large-scale infrastructure construction, which takes a long time to realize. Therefore, non-structural countermeasures, such as information provision, signal control, public transportation promotion, etc., have been conducted for some time to reduce or disperse traffic demand, as is shown in the case of Los Angeles [1]. Nevertheless, it remains difficult to solve the problem of traffic congestion using these methods.

Travel time has long been considered a negative aspect of travelling. Especially for drivers, travel time during traffic congestion is regarded as a psychological burden because of the behavioral and attentional restrictions imposed by driving. Hennessy et al. revealed a positive relationship between traffic congestion and aggressive driving [2], as did Shinar et al. [3]. To deal with the long waiting times that accompany traffic congestion, people are increasingly adopting various Information and Communication Technologies (ICTs). ICT, along with mobile telecommunication technologies and autonomous driving, is advancing rapidly nowadays, and such technologies can potentially reframe travel time as "valuable time." This, in turn, might lead to some form of psychological resolution for serious traffic congestion. In the present study, these technologies are termed "ICTs for enjoying traffic congestion." Considering that car manufacturers, electronics companies, and researchers are now competing to develop travel-related technologies, such as "head-up displays" [HUDs], which allow for projecting information on the front windows of vehicles [4][5], it is necessary to accumulate knowledge on the content of these ICT applications that is desirable for drivers to make use of their time during traffic congestion. In this study, in order to aid in the future development of "ICTs for enjoying traffic congestion," a questionnaire survey was conducted on drivers' activities during traffic congestions. A specific focus was on the target groups and contents of these ICTs.

### *B. Related work*

In the literature on ICT applications for drivers, Siuhi and Mwakalonge reviewed the latest trends and found that route planning, traffic safety, parking information, transportation data collection, and fuel emissions and consumption are the main categories of ICTs for drivers [6]. Among them, route planning information via smartphones appeared to be most acceptable for young drivers [7], and many drivers found stop sign information provision as a traffic safety measure useful [8]. Ilarri et al. introduced the present course of development of applications for vehicular ad hoc networks (VANETs) using extensive references [9]. However, there are no studies, to our knowledge, on developing ICTs to reduce drivers' psychological burden during congestion.

Psychology researchers have identified several factors that can shorten human time perception. Particularly, Maister noted that "the more valuable the service, the longer the customer will wait" [10]. In exploring what qualities make a service "valuable," Failing, et al. revealed that services with

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"higher reward" might induce attentional deployment and shorten people's subjective time [11]. Furthermore, Edwards, et al. found that "high intensity exercise" in sports can shorten subjective time [12]. Misuraca et al. examined groups of maximizers and satisficers, and found that maximizers (who generally choose the option with the highest expected utility) tend to perceive time as shorter during the "decision-making" process than do satisficers (who generally choose the "good-enough" alternative) [13]. From the viewpoint of enjoyment, Sackett, et al. found that time passes more quickly during enjoyable experiences [14], and Xu, et al. mentioned that switching between more and less entertaining tasks can generate overestimation of time duration [15]. So far, there is little research focusing on drivers' time perception.

Therefore, our proposed concept of "ICTs for enjoying traffic congestion" can be considered new and requiring further study as a potential intervention for the psychological burden experienced by drivers in serious traffic congestions.

### C. *Outline of this work*

The outline of this work is as follows. Section II provides an overview of the questionnaire survey. Section III introduces the statistical results of the survey, including several activity choice models. Finally, the conclusions and suggestions for future work are mentioned in Section IV.

## II. Survey Overview

In this section, an overview of the web questionnaire survey is described.

### A. *Sample selection*

In this paper, a web-based questionnaire survey was conducted to understand drivers' activities to pass the time during serious traffic congestion. To investigate the variety of actual behaviors, this method is considered to be more realistic and cost-effective for collecting data about drivers' experience than in-situ observations conducted by equipping drive recorders to sample vehicles. Considering the research objective, respondents with driving experience in traffic congestion were desired. Therefore, the survey was conducted via a web-based research company. Their monitors were screened using three criteria: have a drivers' license, have more than one year of driving experience, and have experienced being caught in a severe traffic jam. The respondent pool was also limited to those aged 20–59 years, in consideration of the age-related declines in driving skills. The percentage of respondents in each age group (20–29, 30–39, 40–49, and 50–59) was set to be 25% by the survey company. The size of total valid samples was 311. An outline of the questionnaire and inclusion criteria are provided in Table I. Since the sample size appears to potentially have insufficient power, we decided that the current number of participants could serve as a preliminary trial to gain a rough understanding of drivers' activities.

### B. *Questionnaire item details*

As shown in Table I, the questionnaire asked respondents about their activities in the car during the most serious instance of traffic congestion ever experienced, along with their personality and driving tendencies. When a serious traffic jam is expected, a driver must leave after considering how to spend that time. Therefore, we determined that even this method can collect drivers' needs and opinions. Details of these items are introduced in the following three subsections.

TABLE I. OVERVIEW OF THE WEB QUESTIONNAIRE SURVEY

| Date | January 5–6, 2018 |
|---|---|
| Inclusion criteria | 1) Driver's license holder<br>2) Individuals with driving experience<br>3) Individuals with experience of being caught in traffic congestion |
| Effective samples | Total valid sample: 311 (male = 147, female = 164)<br>Percentage of each age group:<br>25% (20–29), 25% (30–39), 25% (40–49), and 25% (50–59) |
| Contents of the questionnaire | |
| (1) Congestion situation concerning the most serious traffic jam ever experienced: time duration, speed, with/without passengers, etc. | |
| (2) Activities in the car during the traffic jam (multiple answers were allowed) | |
| (3) Personality traits and tendencies while driving | |

#### 1) *Activities in the car*

Respondents' activities in the car during the traffic congestion were categorized as active activities and passive activities. Active activities refer to activities requiring specific motions to perform, while passive activities are activities that do not require such motions. In the survey, specific activities were set for each category to standardize the responses, as follows. Respondents were simply asked to indicate if they had experienced each activity or not during the most serious traffic congestion that they had experienced.

- Active activities: making conversation, eating snacks, singing, playing mobile games, surfing the web, telling funny/horror stories, and answering riddles/quizzes
- Passive activities: listening to music, watching TV, and listening to the radio

#### 2) *Personality*

Items were prepared to assess drivers' personalities by referring to the egogram proposed by J. M. Dusay in the field of transactional analysis in personality psychology [16]. Egogram is an easy and compact method of creating questionnaire items while considering the burden on respondents. The egogram involves dividing individuals' personalities into five factors (controlling parent [CP], nurturing parent [NP], adult ego state [A], free child [FC], and adapted child [AC]). The meaning of each factor and their specific items are shown in Table II. Three items were selected from among ten original items for each factor in accordance with the survey context. Each item is rated on a 6-point Likert scale: 1 = disagree, 2 = moderately disagree, 3 = slightly disagree, 4 = slightly agree, 5 = moderately agree, 6 = agree).

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TABLE II. ITEMS FOR EACH OF THE FIVE PERSONALITY FACTORS

| Factor | Meaning | Measuring questions |
|---|---|---|
| CP: Controlling parent | Sense of justice, moral, responsibility, etc. | - I stick to my own way rather than go along with others.<br>- I'm strict on promises, rules, and times.<br>- I clearly say whether I am for or against |
| NP: Nurturing parent | Tenderness, kindness, acceptability, etc. | - I am not able to refuse somebody's request.<br>- I'm an obliging person.<br>- I often pamper others unintentionally. |
| A: Adult ego state | Intelligence, logicality, etc. | - I usually don't waste money and time.<br>- I do not get disturbed emotionally.<br>- I firmly make plans in everything. |
| FC: Free child | Activeness, creativity, curiosity, etc. | - My mind is always filled with ideas and plans that have not been fully considered.<br>- If I think of anything, I act fast.<br>- I like to liven up the atmosphere by joking. |
| AC: Adapted child | Cooperativity, tolerance, politeness, etc. | - I act cautiously in everything<br>- I usually care about the words and attitudes of others.<br>- I often cannot express what I think. |

*3) Driving tendencies*

Items to assess driving tendencies in general and during traffic congestion were created with reference to Fujimoto's driving scale [17], supplemented with items related to their tendencies during traffic congestion, such as cellphone operation. All items are shown below. Each item is rated on a 6-point Likert scale (the same one as for personality).

[In general]

- *Confidence in driving*: I'm confident in driving and can concentrate on driving.
- *Fond of driving*: I'm fond of driving.
- *Use of detours*: I actively use detours.
- *Attentive driving*: I rarely drive inattentively.
- *Manner compliance*: I usually keep traffic manners and rules more than others.
- *Driving without a break*: I often drive without taking a break.

[During traffic congestions]

- *Use of cellphone*: When I get caught in traffic jams, I unintentionally pass the time by watching my cellphone.
- *Quick to irritate*: I get irritated immediately even in a light traffic jam.

## C. Survey hypotheses

The following two hypotheses were devised.

a) Drivers' personality factors and driving tendencies affect how they pass the time during traffic congestion.

b) The existence of passengers and the seriousness of the traffic congestion influence drivers' choice of active activities.

# III. RESULTS

The following sections outline the results of the statistical analyses.

## A. Situations of traffic congestions

Figure 1 shows the distribution of trip purposes and whether there were passengers in the car or not when the respondents encountered the serious traffic congestion. The percentage of trips with passengers along with each trip's purpose are also shown in the figure. The most frequent purpose was "sightseeing/trip," and most respondents who provided this answer noted that there were passengers in the car with them. On the other hand, in the case of "business" and "commuting," respondents were less likely to have passengers compared with the other purposes. It was thought that for these purposes, respondents might have been more irritable and sensitive to delay than for other purposes because of their arguably greater schedule constraints and ill-preparedness for serious traffic congestion; respondents' choice tendencies might also differ for these purposes than for the others. Therefore, for all further analyses, these two purposes were excluded from the samples.

Figure 2 shows the distribution of the congestion durations

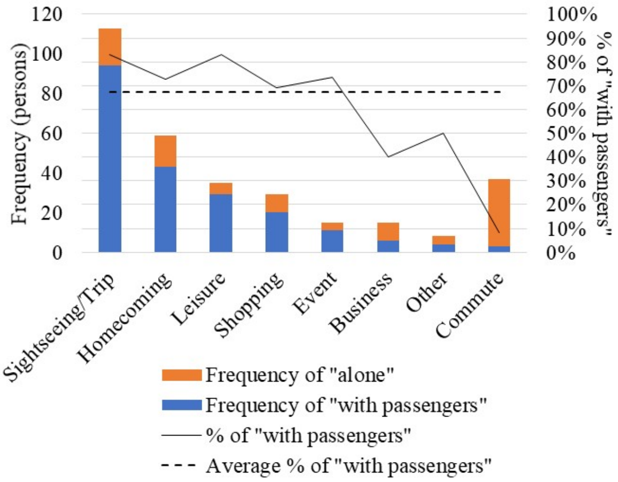


Figure 1. Trip purposes and the existence of passengers in serious traffic congestion ($N = 311$)

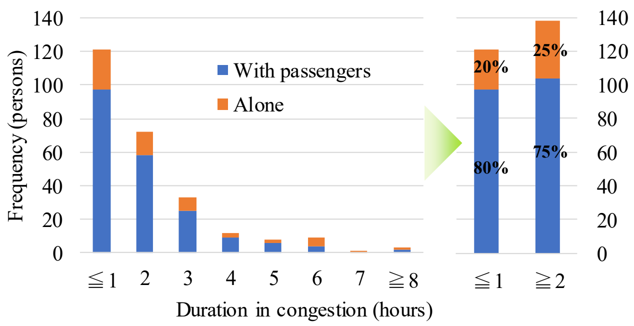


Figure 2. Distribution of congestion duration and its relation to existence of passengers ($N = 259$)

according to whether there were passengers in the car. Notably, the majority of respondents reported their most serious congestion as lasting for one hour or less. If congestion duration was divided into two groups—one hour or less and two hours or more—the frequencies were roughly equal. The proportion of respondents with passengers was also similar between these two groups ($t$ = 0.925, $p$ = 0.356). Thus, for subsequent analyses, the sample was divided into two categories: "one hour or less" and "two hours or more."

Participants also were asked to report the perceived speed of the traffic congestion using two categories: "slowly move" (assumed to be congestions caused by traffic concentration in expressways) and "hardly move" (assumed to be congestion caused by accidents or other cases). The distribution of congestion duration, existence of passengers, and speed is shown in Figure 3.

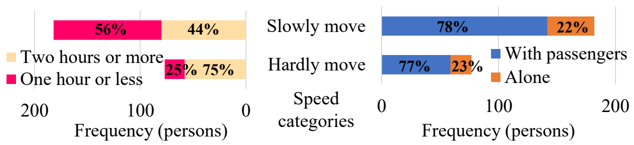


Figure 3. Congestion duration, existence of passengers, and speed categories ($N = 259$)

The ratios of the existence of passengers were the same in both speed categories ($t$ = 0.247, $p$ = 0.805), significantly higher for the "hardly move" category ($t = 4.62$, $p \leq 0.01$).

## B. Distribution of driving tendencies

Figure 4 shows the results of respondents' driving tendency. In general, they appeared to have a high level of manner compliance and like to drive without a break. For driving tendencies during congestion, 32% of respondents reported using mobile phones and 48% reported becoming irritated. As these percentages were higher than was the percentage of individuals with low manner compliance (22%), it seems that manner compliance is not directly linked to actual behaviors in traffic congestion. This result suggests that it is more important to ensure their safe and effective use of time and the reduction of their psychological burden via ICTs than to improve their manners.

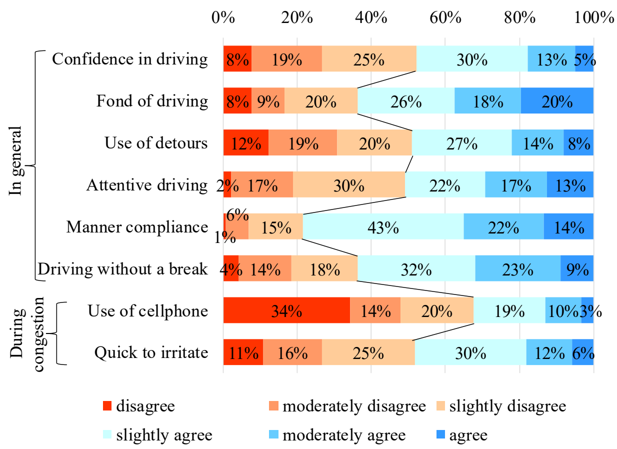


Figure 4. Distribution of responses for driving tendencies ($N = 259$)

## C. Activity choices during traffic congestion

For this analysis, "conversation" was separated from the other active activities because a high proportion of respondents selected it when there were passengers in the car. Therefore, activities were re-categorized as conversation, active activities, and passive activities.

Figure 5 shows how respondents passed their time in the cars during serious traffic congestions according to whether there were passengers in the car or not. When there were passengers, almost 80% of respondents selected conversation. However, if the drivers were alone ($n$ = 58), approximately 20% did nothing. Moreover, 40% of respondents with passengers selected active activities, whereas less than 20% selected such activities if they were alone. Although the percentages of those who chose passive activities were high, regardless of the existence of passengers, a high proportion of respondents chose passive activities, especially if they were alone. Based on these findings, it is possible to assume that conversation and active activities were preferable to drivers when they were with passengers, while some drivers appeared to not pursue any activity when they were alone.

## D. Personality factors affecting active and passive activities

Table III shows the average score for each personality factor when dividing respondents according to their choice of activities. The scores of each personality factor were normalized to range from 0 to 1, with 0 denoting a low score and 1 denoting a high score. The FC factor appeared to be a dividing factor for active and passive activities: that is, those who chose active activities had higher FC scores. When focusing on passive vs. non-passive activities, the CP and A scores significantly differed.

## E. Activity choice model

Logistic regression analyses were conducted to explain what factors were related to respondents' choice of active and passive activities.

### 1) Choice model for active activities

The above analyses revealed that the existence of passengers and the FC personality factor were influential in

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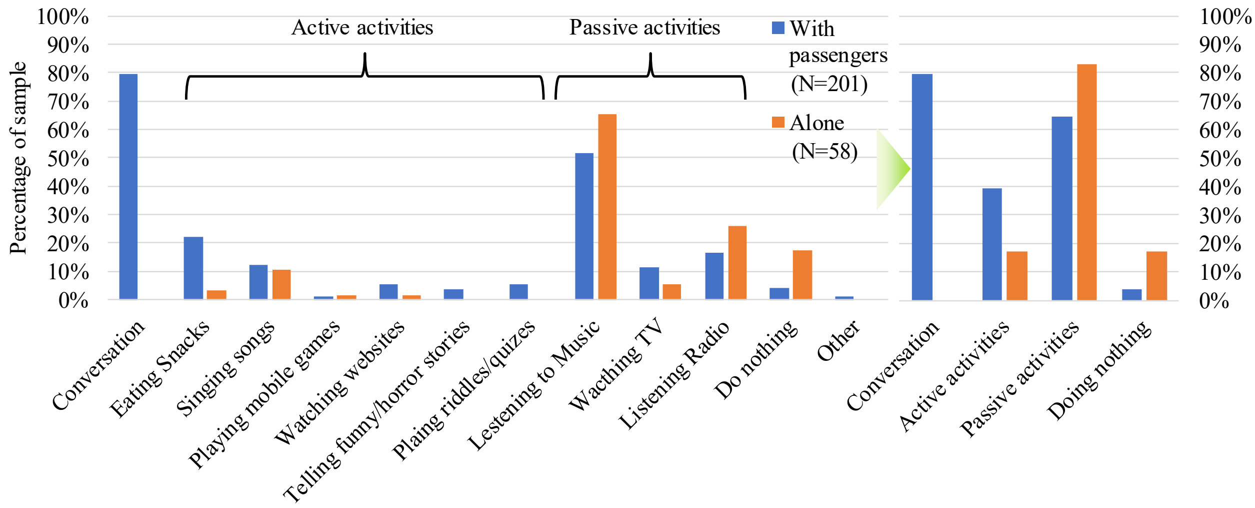


Figure 5. How to spend in cars in serious congestions

TABLE III. COMPARISON OF AVERAGE VALUES OF PERSONALITY FACTORS ACCORDING TO ACTIVITY CHOICE

| Personality factor | Active and passive $df = 265$ | | | Active and non-active $df = 257$ | | | Passive and non-passive $df = 257$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | Active ($N = 89$) | Passive ($N = 178$) | | Active ($N = 89$) | Non-Active ($N = 170$) | | Passive ($N = 178$) | Non-Passive ($N = 81$) | |
| CP | 0.57 | 0.57 | | 0.57 | 0.54 | | 0.57 | 0.51 | ** |
| NP | 0.54 | 0.52 | | 0.54 | 0.51 | | 0.52 | 0.51 | |
| A | 0.53 | 0.54 | | 0.53 | 0.52 | | 0.54 | 0.49 | ** |
| FC | 0.54 | 0.50 | * | 0.54 | 0.46 | *** | 0.50 | 0.47 | |
| AC | 0.59 | 0.58 | | 0.59 | 0.59 | | 0.58 | 0.60 | |

*: P<0.10, **: P<0.05, ***: P<0.01

the selection of active activities. Therefore, a logistic regression analysis was conducted (see Table IV) to clarify how personality factors, the existence of passengers, the congestion situation, and driving tendencies influenced the selection of active activities.

The coefficients were estimated using a significance probability of 90% and the stepwise method, and the analyses were carried out separately by congestion duration ("one hour or less" and "two hours or more"). The findings from the analysis were as follows.

*a) Factors related to active activities during short-term congestions*

In short-term (one hour or less) traffic jams, active activities were significantly more likely to be chosen by drivers who used their mobile phones during congestion and who have high manner compliance (see Table IV). Furthermore, despite the above findings, the existence of passengers and FC scores did not have a significant association with active activities.

*b) Factors related to active activities during long-term congestions*

Unlike the results for the short-term congestions, the existence of passengers and FC scores did significantly relate to selection of active activities during long-term congestions (two hours or more). In addition, when the traffic jam was

TABLE IV. ACTIVE ACTIVITY CHOICE MODEL ACCORDING TO CONGESTION DURATION

| Variable | | 1 hour or less | 2 hours or more |
|---|---|---|---|
| Frequency | Active actions | 40 | 49 |
| | Non-Active | 81 | 89 |
| Output of binary logit model | | Coefficients | Coefficients |
| | Intercept | -3.72 *** | -1.87 |
| Situation of congestion | Hardy move | | 1.27 *** |
| | With other passengers | | 1.93 *** |
| Personal Attribute | Age | | -0.07 *** |
| Personality factors | FC | | 3.56 *** |
| Driving tendencies | Manner compliance | 0.43 ** | |
| | Use of cellphone | 0.44 *** | |
| Accuracy of the model | Likelihood ratio $\chi^2$ | 11.18 *** | 38.69 *** |
| | Hit ratio | 65.3 | 80.3 |

*: P<0.10, **: P<0.05, ***: P<0.01

"hardly moving" and respondents were young, respondents had a stronger tendency to select active activities.

*c) Comparison of active activity models between short- and long-term congestions*

Comparing the choice models for short- and long-term congestions revealed that active activities were significantly more influenced by drivers' driving tendencies in short-term congestions, while in long-term congestions, they were significantly more influenced by drivers' personality factors, age, and congestion situations. These results suggest that when developing new ICTs for drivers, it is necessary to understand that the factors that must be considered might change according to the duration of the traffic congestions.

*2) Choice model for passive activities*

In contrast to active activities, passive activities were adopted more frequently when drivers were alone. As shown in Table III, CP and A scores were significantly related to choice of passive activities. Therefore, a logistic regression analysis was conducted again in the same way as in the previous section. The results are shown in Table V.

*a) Factors related to passive activities in short-term congestions*

As shown in Table V, it is clear that respondents tended to select passive activities when driving alone in short-term congestions. Notably, none of the personality factors were significant (like the results for active activities). Furthermore, drivers who reported that they liked to drive and could tolerate traffic jams tended to select passive activities.

TABLE V. PASSIVE ACTIVITY CHOICE MODEL ACCORDING TO CONGESTION TIME

| Variable | | 1 hour or less | 2 hours or more |
|---|---|---|---|
| Frequency | Passive action | 76 | 102 |
| | Non-passive | 45 | 36 |
| Output of binary logit model | | Coefficients | Coefficients |
| | Intercept | 1.81 * | 1.91 * |
| Situation of congestion | With other passengers | -2.22 *** | |
| Personal Attribute | Age | | -0.05 ** |
| Personality factors | CP | | 2.23 * |
| Driving tendencies | Fond of driving | 0.51 *** | |
| | Use of detours | | 0.33 ** |
| | Quick to irritate | -0.36 ** | |
| Accuracy of the model | Likelihood ratio $\chi^2$ | 27.05 *** | 12.17 *** |
| | Hit ratio | 75.9 | 70.7 |

*: P<0.10, **: P<0.05, ***: P<0.01

*b) Factors related to passive activities in long-term congestions*

In long-term congestions, the existence of passengers was not significantly related to passive activity choice. Among the personality factors, only CP scores was significantly related. Finally, drivers that tended to use detours often preferred passive activities.

*c) Comparison of passive activity models between short- and long-term congestions*

The previous analysis suggested that both CP and A scores influenced passive activity choice. However, the regression analysis showed that only CP score was related to passive activity choice, and only in long-term congestions. One possible reason for this is multicollinearity. The correlation coefficient between CP and A was 0.273, which is considered a weak correlation in psychology research. Multicollinearity was tested for in other respects, and it revealed no other problems. Furthermore, as in the case of active activities, personality factors related to the choice of passive activities only in long-term congestions. When drivers were alone in short-term traffic congestion, they appeared more likely to choose passive activities.

*3) Comparison of the two activity choice models*

Figure 6 provides a summary of the activity choice models with path coefficients for the factors significantly related to active and passive activities. The solid lines denote positive effects and the dotted lines denote negative effects. In addition, the thickness of the lines expresses the significance level of the path coefficient.

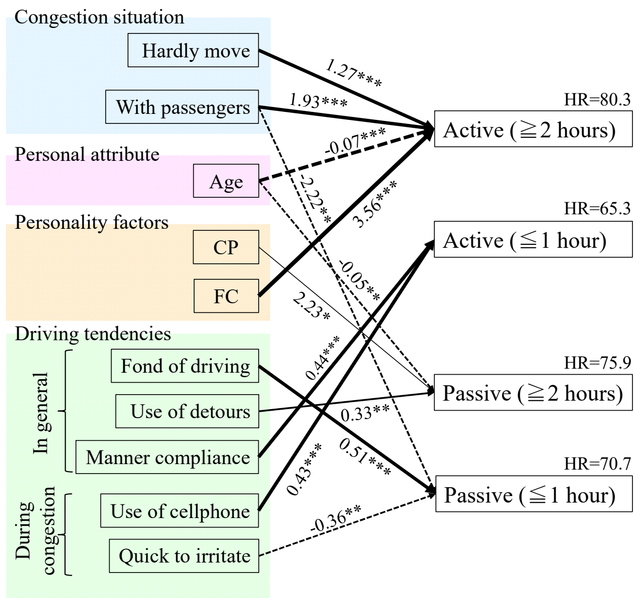


Figure 6. The summary of the activity choice models

The results showed that drivers' personal attributes and personality factors had significant associations with activity choice only during long-term traffic congestions, whereas driving tendencies had significant relations only for the short-time traffic congestions. It therefore seems natural that drivers that tend to use mobile phones during traffic congestions might choose active activities in short-term congestions. However, a surprising finding was that during short-term traffic congestions, higher manner compliance was associated with selection of active activities, which included some activities deemed illegal while driving (e.g., surfing the web, playing mobile games). It is possible that individuals with higher manner compliance do try to find legal active activities to pass the time during traffic congestions.

## IV. Conclusion and Future Work

This web-based questionnaire survey of drivers was designed to identify activities used to pass the time during serious traffic congestions, and clarify the factors that related to the choice of active and passive activities. Conversations were found to be effective for passing the time for most drivers with passengers. The activity choice models also revealed that drivers without passengers tended to choose passive activities in short-term traffic congestions, while drivers with passengers tended to choose active activities during long-term congestions. Therefore, it seemed important to promote active activities, including conversation, when there are passengers in the car. In addition, when focusing on long-term congestions, younger drivers and drivers with higher FC scores tended to select active activities.

Based on these results, one of promising future targets for ICTs aimed at helping drivers pass the time during long-term traffic congestion are "young people with passengers." The use of ICTs might be particularly helpful for traffic congestions that are "hardly moving." Once a target is determined, it becomes clear what type of content should be developed to promote the drivers' actions in the cars. It can be an expected technology, for example, to offer conversation automatically based upon the passengers' attributes and preferences.

On the other hand, when focusing on short-term traffic congestions, drivers' driving tendencies had a stronger influence on their activity choice compared personality factors. In addition, some passengers who were alone did not choose any activity. Because even drivers with high manner compliance tend to engage in active activities, such as using cellphones, which is considered an unsafe behavior, during short-term congestions, it might also be necessary to develop ICTs that can help drivers effectively pass their time safely. A handsfree quiz function with voice recognition can be one of the solutions.

The future tasks in this area are the development of apps for drivers that conform to legal restrictions, and checking to what extent these apps gratify drivers under severe traffic congestions. In general, drivers cannot use most existing apps and games since watching screens is a traffic violation. Therefore, future apps for drivers should be primarily operated by drivers' voice. It is important, of course, that such apps keep drivers' attention on their driving, without immersing them too deeply in the app. In Japan, it is said that drivers are so disciplined that comparatively immersive apps of "ICTs for enjoying traffic congestion" might be applicable. However, when providing such apps to drivers, it is critical to understand the cultural backgrounds of cities where they are introduced.

## Acknowledgment

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# Exploring Origin and Rotation Parameters While Using Hilbert Curves in Mobile Environments

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***Abstract*—In mobile computing, nearest-neighbor queries are of the form "find me the nearest service of type $S$" or "find me $k$ nearest services of type $S$." It is known that such queries, while convenient for the consumer, are associated with privacy threats. For addressing such privacy threats, one of the approaches suggested by researchers is spatial transformation via Hilbert curves. A Hilbert curve fills a 2-dimensional grid with a one-dimensional sequence that may be viewed as a curve. It is thus usable as a hash function that is order-preserving, in the sense that adjacent elements in the single dimension represent physically contiguous space in two dimensions. It provides an encryption of the two-dimensional space coordinates with the parameters involved in its construction serving as the *key*. The origin of the two-dimensional grid that is conceptually overlaid on the physical space and the choice of two canonical forms of the curve are crucial elements of the key. In this paper, we examine the ramifications of these parameters on the Quality of Service (QoS) provided to mobile users and suggest that these parameters be chosen based on acceptable QoS thresholds. By considering rotation and transposition, we enhance the space of keys, thus providing more options in the choice of those parameters.**

***Keywords*–*Mobile Privacy; Spatial Transformation; Hilbert Curves; Location-Based Queries; Location-Based Service.***

## I. INTRODUCTION

Privacy is a challenge in mobile environments. Users are happy with location-based queries of the form "find me the nearest service of type $S$" or "find me $k$ nearest services of type $S$." Unfortunately, their satisfaction is reduced by the underlying threat to their privacy. One of the two main approaches suggested by researchers for addressing this threat involves spatial encoding via Hilbert curves. The idea is that the *Location Based Server (LBS)* handling these user queries can be made unaware of the actual geographical coordinates of the users, the Points of Interest (POIs), and the categories of those POIs (e.g., restaurant, gas station), by being provided encoded spatial coordinates instead of actual geographic coordinates and encrypted identifiers instead of plaintext categories by another server, a trusted one (referred to as *Trusted Server (TS)*). The spatial encryption seems infeasible to break (invert) because of the large number of possible keys, i.e., ways the curve construction parameters can be chosen. In this paper, we explore the effect on the end-user of the choice of two of those parameters: origin and rotation, by defining QoS metrics around them; and propose an optimal strategy for their selection using quantitative thresholds.

### A. Introducing the Hilbert Curve

A *Hilbert curve* is a space-filling transformation of bounded 2-dimensional space. Assume that a square space is divided into $2^{2N}$ cells arranged in a $2^N \times 2^N$ grid. A Hilbert curve $H$ of order $N$ is defined by a bijective function $h$ that maps each $(x, y)$ pair, where $x$ and $y$ are integers in $0 \cdot\cdot (2^N - 1)$, into an integer in $0 \cdot\cdot (2^{2N} - 1)$. Figure 1 shows an example with $N = 3$ (i.e., an 8x8 grid); values of $h$ for each cell is shown within it; the sequence $0 \cdot\cdot 63$ defines a curve that fills the grid passing through each cell exactly once. By abuse of notation, we will use this function $h$ to refer to the curve $H$ as well. The bottom left cell corresponds to the origin of the $X$-$Y$ coordinates. We also refer to the map as a 2-dimensional matrix: In Figure 1, $H[0, 0] = 0$; $H[1, 0] = 1$; and $H[0, 1] = 3$. Figure 2 shows a *transposed* curve with a similar logic but starting with cells $0 \cdot\cdot 3$ numbered anticlockwise. Since $H[i, j]$ in this transposed curve is equal to $H[j, i]$ in the normal curve, this is essentially a matrix transpose operation (the original paper [10] described it as *rotated*). Hence, we are calling it a transposed curve. Rotated representations of the curve are in Figures 3 (90°), 4 (180°), and 5 (270°).

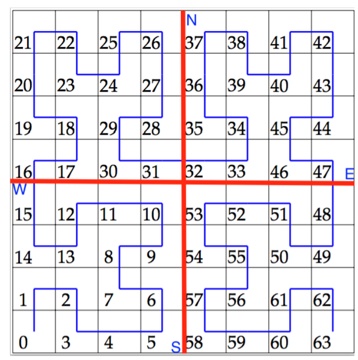


Figure 1. Normal Hilbert Curve for $N = 3$. The bottom row and leftmost column correspond to row 0 and column 0 of the corresponding matrices.

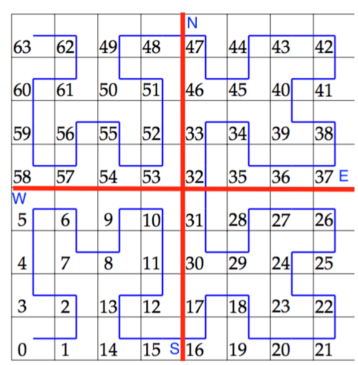


Figure 2. Transposed Hilbert Curve for $N = 3$.

This function $h$ is contiguity-preserving (i.e., two cells mapped into $i$ and $(i + 1)$ must represent 2-dimensional spaces that are contiguous). However, $h$ may map contiguous

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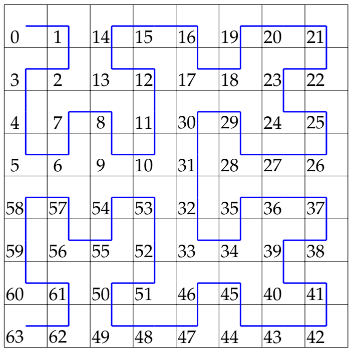


Figure 3. Hilbert Curve for N=3 rotated by 90 degrees clockwise.

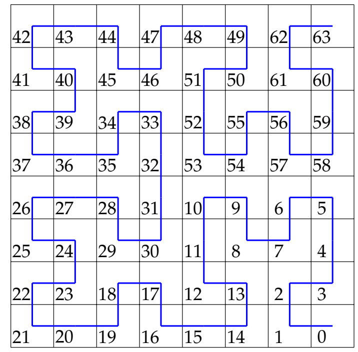


Figure 5. Hilbert Curve for N=3 rotated by 270 degrees clockwise.

cells in 2D-space into Hilbert numbers that are not close (e.g., numerically distant cells 5 and 58 in Figure 1 represent contiguous spaces).

### *B. Utilizing the Hilbert Curve for Location Privacy*

It was first suggested in [10] that a Hilbert curve can be applied to location-based services. Such a Hilbert curve is generated by a Trusted Server (TS) by deciding the curve's parameters. They are: (1) the *order* of the curve $N$; (2) the (physical location of the) point of *origin* $X_0, Y_0$; (3) the *orientation* $\Theta$ (*normal* or *transposed* as in Figures 1 and 2 respectively); and (4) a *scaling factor* $\Gamma$ that captures the number of meters that each unit cell represents (in both figures, $\Gamma$ is the distance in meters covered by the grid in either the X- or Y-direction divided by 8). Using $\Gamma$ and the origin, any geographic location $(x_0, y_0)$ in the 2-D space (which could be represented by latitude and longitude), can be converted into a grid cell $(x_0^*, y_0^*)$, where $x_0^*, y_0^* \in 0 \cdot \cdot (2^{2N} - 1)$. Thus, the transformation parameters (unknown to any adversary) are $[X_0, Y_0, \theta, N, \Gamma]$.

The parameter $N$ is chosen in an effort to maintain a low average number of POIs per cell ($\frac{POI}{H}$ ratio); $N$ is increased until that ratio is less than a given threshold. Some have suggested a hierarchy of curves with different $N$ when the POI distribution varies markedly across the region [3] [15].

With knowledge of the map of the area and POIs, the TS first converts the geographical coordinates of each POI into a corresponding Hilbert cell number (in $0 \cdot \cdot (2^{2N} - 1)$); and next, using an encryption key $e$, it encrypts the description of the POI as well as its *category* or *domain* (e.g., restaurant) and *subcategory* (e.g., Vietnamese). Thus, the TS generates the

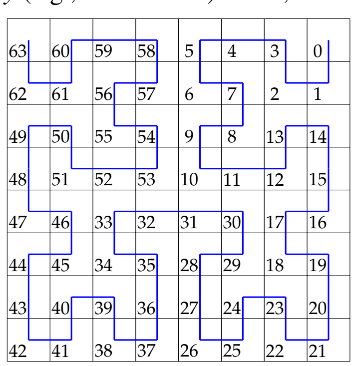


Figure 4. Hilbert Curve for N=3 rotated by 180 degrees clockwise.

curve $H$, creates a table of POIs of the kind shown in Table I, and sends it to the LBS, which uses it to answer location-based queries from users. Disruption of services from the TS and LBS can be avoided by using the well-known strategy of replication of servers and storage.

TABLE I. TABLE $T$ SENT FROM THE TS TO LBS.

| Cell | POI description | Category | Subcategory |
|---|---|---|---|
| 43 | 05A4C3BB02F568489 | 9A4027D | 4715 |
| ... | ... | ... | ... |
| 16 | 47923CC19B6C71AA0 | 7399BBA | 02AA |

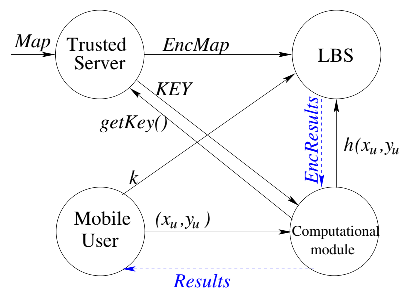


Figure 6. Interaction among actors to process a user query.

A mobile user queries the LBS using the Hilbert cell number corresponding to his/her location's two-dimensional coordinates; the LBS searches for the numerically closest Hilbert cell number that contains appropriate POIs and returns them to the user. A computational module obtains the transformation parameters from the TS by sending a *getKey()* request; transforms the user's geographic location $(x_u, y_u)$ (e.g., latitude, longitude) into a grid cell $(x_u^*, y_u^*)$, and then applies $h()$ to obtain a Hilbert cell number $h(x_u^*, y_u^*)$; and also decrypt the returned POI descriptions using the inverse of $e$. To perform the above mentioned steps, this module needs a *KEY* from the TS:

$$KEY = \{[X_0, Y_0, \theta, N, \Gamma], \;\; e^{-1}\}. \qquad (1)$$

The practical implementation of the system is feasible in terms of performance because (a) the generation of the curve is done offline; (b) at the LBS, the POI retrieval is a range query that can exploit a B+ tree; [8] and (c) at the computational module, the computation of a Hilbert cell number can be done in time $O(n)$ or faster [2].

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### C. The Problem

We have found it useful to represent the overall scheme using Figure 6; by exploring the knowledge available to the four agents, we have argued elsewhere [16] that the computational module must reside in the user's device while remaining opaque to the user.

Now, the restriction on $\frac{POI}{H}$ mentioned above often dictates the determination of $N$ and $\Gamma$, i.e., the placement of the $2^N \times 2^N$ grid on the physical map, making the number of choices of the origin and rotation crucial for a robust encryption. So, the question we ask is the following: assuming the grid is decided and the only variables are the origin and $\theta$, what are the ramifications of the choices? Can the origin be moved to any cell in the grid? This leads to the question, are there cells in the grid that can remain unused, i.e., unmapped by the Hilbert curve? The answer is *no* when every grid cell is a potential POI location and cannot be ignored; the answer is *yes* when the fringe areas of a city consist of uninhabited open spaces or mountains or streams.

When the answer is *no*, we explore a wraparound scheme for re-indexing unmapped cells. Since this has the potential of degrading the nearness of returned POIs, we have used a QoS measure and found a correlation between the defined QoS measure and the number of contiguity violations.

When the answer is *yes*, the number of unmapped cells is a QoS measure; it can increase dramatically for many choices of origin. Here, we have outlined an opportunistic shift-plus-rotation scheme that reduces the degradation considerably. Thus, in both cases, origin shifts can be chosen based on a quantifiable acceptability criteria as well as considerations regarding the importance of those POIs either left unmapped or mapped violating contiguity.

The paper is structured as follows. In section 2, we present related work. In sections 3 and 4 we explore the *no* and *yes* answers respectively. Finally, we present our conclusions and future work in section 5.

## II. Related Work

Abel et al. [1] compare Hilbert curves with four other spatial transformation orderings (row, row prime, Morton and Gray code) for geographical data processing. They conclude that Hilbert curves are poorer than Morton ordering in terms of oversearch for windowing operations but are much better in preserving contiguity. Dai et al. in [4], present an analytical study on the locality properties of Hilbert curves. Moon et al. [14] focus on the curve rotation concept while evaluating the clustering properties of Hilbert curves. They show that the clustering properties of Hilbert curves are better than $z$-order curves for range queries. A shift operation is implemented on the Hilbert curve in [13] and [5] to address the loss of proximity in the Hilbert space introduced by the gap in the *U-pattern*. Liao et al. in [13] introduce multiple shifted copies of the Hilbert curve that are indexed and stored in $(d+1)$ $B$-trees where $d$ is the dimensionality of the space. Dai et al. [5], uses multiple $B^+$-trees for storage of the curves and evaluate range query performance in terms of number of pages accessed.

$k$-anonymity and spatial encoding have been the two primary approaches to address location privacy. In the $k$-anonymity-based approach, the goal is to send an obfuscated region instead of an exact user location ensuring that it contains at least $(k-1)$ other users. Such a region is constructed either by relying on a Trusted Third Party (TTP) with which all users share their exact locations or through a Peer-to-Peer (P2P) approach collaborating directly with $(k-1)$ other users nearby.

Khoshgozaran et al. [11] use a Private Information Retrieval (PIR) technique: the untrusted server does not have complete knowledge of the user's request and related response. But this approach is computationally very expensive.

Kalnis et al. [9] proposed a $k$-anonymity-based Hilbert Cloaking (HC) scheme that generates a cloaked (obfuscated) region using a Hilbert Curve. In [12], Lee et al. address the Hilbert curve's drawback while generating a cloaked region i.e., an extended cloaked region is generated (while using Hilbert curves) due to the disconnect in adjacent cells resulting from the *U-pattern*. Ghinita et al. [7] use Hilbert curves in a P2P setting. Damiani et al. in [6] propose Hilbert curve-based obfuscation. The map knowledge of the adversary and user's privacy preferences are taken into account while creating the obfuscated region over the target encoded space. Niu et al. [15] introduced the FGcloak algorithm that generates Hilbert curves with finer orders based on the query probability in the target region. Thereby, customizing the curve for high query probability regions. Cui et al. [3] propose a Hierarchical Hilbert Curve-based spatial $k$-anonymity that uses the average query density and constructs a hierarchical index to fill layers of the region with a curve.

## III. Origin Shift via Wraparound

Here, we explore the question, can any of the $2^{2N}$ cells be chosen as the origin when no cell can be ignored? This would provide a very large key space — a desirable feature. We refer to this as shifting the origin.

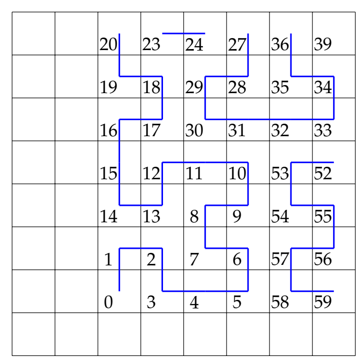


Figure 7. Hilbert curve for $N = 3$ with origin shifted to $(2, 1)$. Unmapped cells are shown blank.

Suppose the origin is shifted to, say, $(2, 1)$; the situation is as shown in Figure 7. The result is that a portion of the grid is empty, i.e., a portion of the geographical area is unmappable and hence inaccessible. Assuming that this is unacceptable, the easiest solution would be a wraparound of the grid that conceives the space as continuous by merging the left boundary with the right and the top with the bottom. In other words, if cell $j$ maps to $(x, y)$ where $x \geq 2^N$, replace $x$ by $x \bmod 2^N$ (similarly $y$). The result is shown in Figure 8 for the origin at $(4, 4)$ and $(2, 1)$. For $(4, 4)$, only three pairs of cells ( (15, 16), (47, 48) and (31, 32) ) become discontinuous (red lines). These violate the contiguity assurance given by the Hilbert curve. Since the LBS is blind to the physical space, such

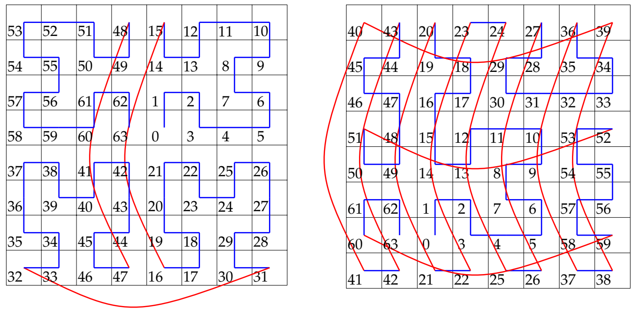

Figure 8. Hilbert curve for $N = 3$ with origin shifted to $(4, 4)$ and $(2, 1)$. Unmappable cells are re-mapped by a wraparound and connected.

discontinuities can result in poor search quality. For example, it may return a POI in cell 48 when the user is in cell 47, perhaps the other end of the city. However, the number of violations is small (only 3). On the other hand, for $(2, 1)$, there are many more red lines indicating multiple discontinuities. Multiple discontinuities indicate a higher probability of poor QoS for the mobile user.

To quantify the effect of the contiguity violations introduced by the origin shift on the mobile user, we use a parameter we call Distance Penalty (D.P.) which was introduced in [10] as Displacement Measure. Assume the user is at location $l_u$ and desires $k$ nearest POIs; D.P. is defined as follows:

$$\text{D.P.} = \sum_{i=1}^{k} \frac{\mid l_u - o_i \mid}{k} - \sum_{i=1}^{k} \frac{\mid l_u - o_i^{'} \mid}{k} \tag{2}$$

where $\mid l_u - o_i \mid$ is the Euclidean distance between the user location $l_u$ and the $i^{th}$ closest POI returned when the LBS searches in Hilbert space, i.e., is kept blind; and $\mid l_u - o_i^{'} \mid$ is the Euclidean distance between $l_u$ and the $i^{th}$ closest POI that would be returned if the LBS was searching in Cartesian space, i.e., was *not* kept blind.

Even when the curve origin is at $(0, 0)$, i.e., is not shifted, and $k = 2$, a certain D.P. is introduced since the Hilbert curve does not exactly preserve the distance between the Cartesian and Hilbert space. We take this to be an acceptable amount based on the POI distribution, user location and $k$ values. We want to measure how much worse it gets as the origin is shifted. We took $N = 3$ and conceived a situation where there was exactly one POI in each Hilbert cell, and the user posed a query from the center of each cell in turn (a total of 64 queries), each time asking for $k = 2$ POIs. (Since there is one POI in each cell, $k = 1$ would be trivial.) Setting up our origin at $(0, 0)$, we computed the D.P. for each query and averaged over all queries. This was $\delta_0$, our baseline D.P. Then we repeated the experiment for $k$ = 3 and 4. Next, we repeated the above for each cell as the origin. After normalizing all D.P. values by dividing by $\delta_0$, we plotted the three D.P. results (for $k = 2, 3, 4$) in Figure 9.

Next, for each origin, we counted the number of pairs of cells that violated the contiguity guarantee (e.g., 3 for the origin at $(4, 4)$); these counts form the last bar in Figure 9. Visually discernible in that figure is our finding that the count of contiguity violations correlates with the D.P. The figure shows that the distance penalty is maximum when the origin is shifted to (3,1) and (5,1), least when the origin shift is (0,0) and (4,0) and varies for different origin shifts. Thus, the D.P. is a QoS metric that the TS can use to control the degradation by rejecting origin shifts for which it is beyond an acceptable value. Moreover, since it is correlated with the number of contiguity violations which is intrinsic to the Hilbert curve, the TS can reject the origin shifts for which those actual violations are unacceptable because they involve high-interest POIs.

## IV. WITHOUT WRAPAROUND

Next, we consider the situation where fringe areas can remain unmapped. The question is, how many cells become unmapped as we move the origin? It is possible to show from the rectangular geometry that when the origin is at $(i, j)$, the number of unmapped cells is given by is given by

$$U = (i + j) * M - ij, \text{ where } M = 2^N. \tag{3}$$

Clearly, this naive method is not feasible when the origin moves to any other quadrant. For example, when the origin is at $(5, 5)$, only 9 cells are mapped and the unmapped cells occupy the central core of the grid not the fringes. Obviously, it would be more practical to rotate the grid. Since POIs inside the unmapped cells become inaccessible as a consequence, their number relates to the QoS.

### A. Combining Shift with Rotation

The original paper [10] had introduced two canonical forms of the curve: the normal and transposed (they called the latter curve *rotated*). Moon et al. [14] introduced two more canonical forms of the curve. Their idea can be explained by flipping the normal curve (Figure 1), which they called $1^+$, about a vertical (horizontal) line running through its middle, i.e., the red line NS (WE) in that figure. After a flip about the horizontal (WE), the resulting shape is changed but after a flip about the vertical (NS), it is not. They called the new shape $1^-$. Similarly, flipping the transposed curve $2^+$ around the vertical line yielded a new curve they called $2^-$. We use their idea but we make use of the unchanged shapes as well because they do yield a different hash function or numbering scheme and that is what we care about. To make this process precise, we propose two orthogonal transformation operators:

1) Transposition, creating $H^T$ from $H$;
2) Rotation by 90°; creating $H^{90}$ from $H$; repeated composition of this provides $H^{180}$ and $H^{360}$ respectively.

The results of rotating the normal curve by 90, 180 and 270 degrees are shown in Figures 3 ($H^{90}$), 4 ($H^{180}$), and 5 ($H^{270}$) above. Similar rotations for the transposed curve ($H^T$) are not shown for shortage of space.

The following can be proved (though we omit the proofs for shortage of space). For a Hilbert curve $H$ ($= H^0$), any integer $n \geq 0$, $\theta \in \{0°, 90°, 180°, 270°\}$ and where raising to a power $n$ means repeated composition:

$$((H^\theta)^T)^T = H^\theta \tag{4}$$

$$(H^\theta)^n = H^{n\theta \bmod 360} \tag{5}$$

$$(H^T)^\theta = (H^\theta)^T \tag{6}$$

$$(H^T)^\theta \sim H^{\theta+90} \tag{7}$$

where $H \sim H'$ means that $H, H'$ are related (by shape symmetry) through the following:

$$H'[i, j] = (2^N - 1) - H[i, j] \tag{8}$$

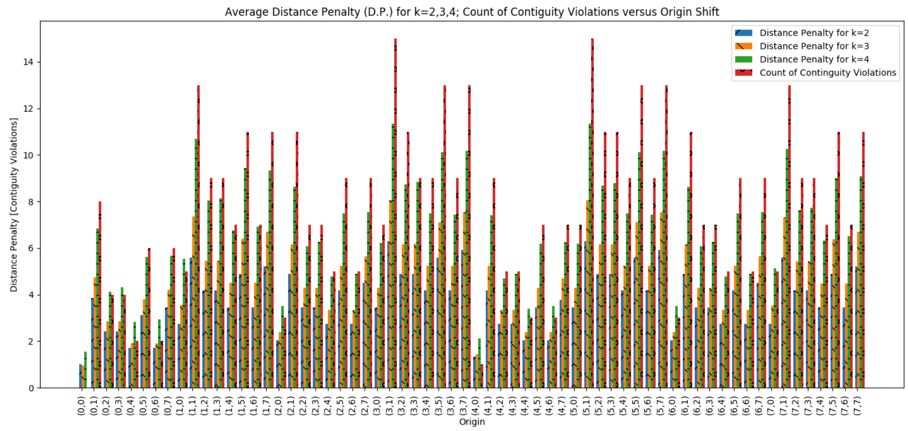


Figure 9. Contiguity Violations and (Normalized) Distance Penalty versus Origin Shift.

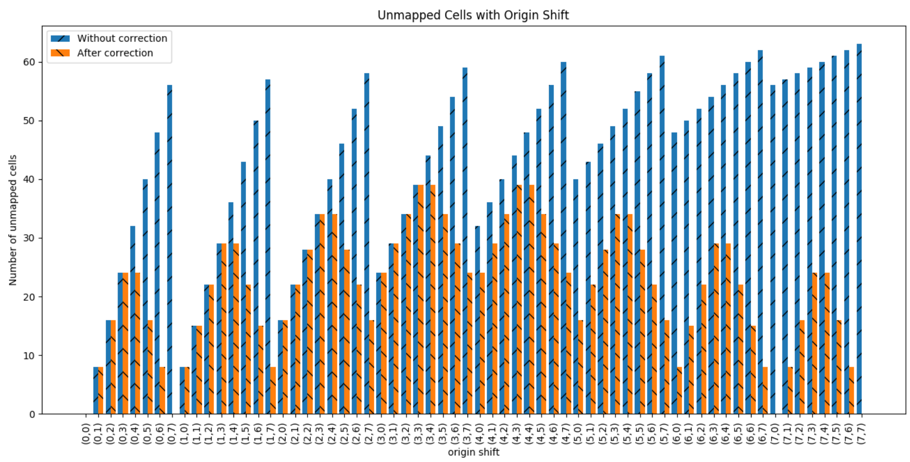


Figure 10. Number of unmapped cells with naive shift and opportunistic shift+rotation.

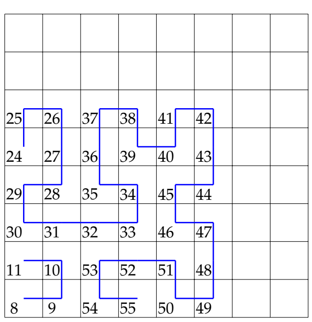

Figure 11. Instead of shifting the origin to $(5, 5)$ and leaving 86% of the cells unmapped, an opportunistic shift strategy allows better coverage. Notice that this effectively shifts the origin to $(-2, -2)$.

Equation 6 allows us to replace both $(H^T)^\theta$ and $(H^\theta)^T$ by $H^{T,\theta}$. In equation 7, the $\sim$ is especially interesting. It shows that pairs of these transformed curves are similar (capturing the similarity in shape) though not identical. Moreover, they involve a swap of origins: the equation shows that 0 is swapped with 63. Such curves, which are similar but not identical are very useful to us because they provide another hash function, i.e., another key combination for encryption. Thus, we obtain 8 canonical forms:

$$\{H, H^T\} \cup \{H^\theta, H^{\theta,T} \mid \theta \in \{90°, 180°, 270°\}\}. \quad (9)$$

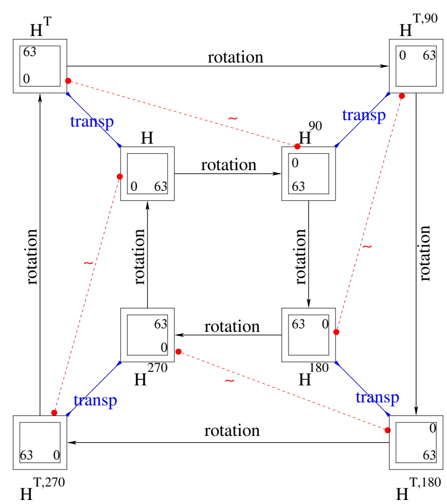


Figure 12. Transformations and Relations among 8 canonical forms.

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Figure 12 indicates the relationships (rotation, transposition, and $\sim$) among all eight. Within each square is a thumbnail of the $8\times8$ matrix showing only the positions of the two end cells: 0 and 63. It is important to note that these eight canonical forms incorporate origin shift: each of the four corner cells is an origin in exactly two of the eight.

### *B. Opportunistic Shifting with rotation*

Now we wish to apply the above operators for arbitrary origin shifts in order to make the shift useful in leaving only the fringe unmapped and in reducing the number of unmapped cells. We propose an opportunistic origin shift. Suppose the origin is to be shifted to $(i, j)$. Depending on the quadrant $(i, j)$ occupies, we choose any one of the 8 canonical curves, find the cell in its outermost corner that is nearest to $(i, j)$, and drag (translate the grid) it to $(i, j)$. For example (Figure 11), when the origin is shifted to $(5, 5)$, instead of leaving out 86% of the grid unmapped, let us choose the normal curve $H$ as the canonical curve; since cell 42 is the outermost corner of $H$ nearest to $(5, 5)$, we translate $H$ dragging cell 42 to $(5, 5)$. Note that the origin is now effectively $(-2, -2)$. (If we had chosen $H^{180}$ or $H^{T,180}$ instead of $H$, the origin would have been at $(5, 5)$.) This along with the choice of any of the 8 forms demonstrates that we have expanded on the space of possible keys. The key now includes boolean $T$ and $W$, transposition and wraparound flags:

$$KEY = \{[X_0, Y_0, \theta, T, W, N, \Gamma],\ \ e^{-1}\}. \qquad (10)$$

Figure 10 shows the number of unmapped cells with and without this scheme (labeled *correction* in the figure). It shows that this scheme is very effective at reducing the number of unmapped cells. The TS can reject certain origin shifts in either of two ways: if the number of unmapped cells exceeds an acceptable threshold, or if those unmapped cells contain high-value POIs. The opportunistic scheme clearly gives a much better set of options in this choice.

## V. Conclusion and Future Work

In this paper, we explored two parameters underlying the Hilbert curve: the origin and 'rotation'. The ability to choose among many values of these two parameters is crucial because we are often constrained in our choice of the others. We considered two scenarios: in the first, it is *not* acceptable to leave some cells unused, i.e., every cell needs to be used; and in the second, it *is*, e.g., when fringe areas of a city do not have useful POIs.

For the first scenario, we introduced a wraparound strategy for varying the origin parameter $(X_0, Y_0)$. This works quite well for some choices of origin but not for others. We quantified this QoS issue using a D.P. metric and found that it correlates with the number of contiguity violations resulting from the origin shift. For the second scenario, the number of unmapped cells is our QoS metric. We introduced transformation primitives that clarified the process of combining rotation with origin shift, enlarged the number of canonical curves from four to eight, and enabled our opportunistic shift with rotation which greatly improved the number of unmapped cells.

In both cases, we enable the TS to choose the origin shifts not only by thresholding the QoS metric, but also by checking if high-interest POIs are among the cells suffering contiguity violations or being left unmapped. Further, by increasing the number of canonical forms and allowing the origin to move outside the grid, we have expanded the space of keys, thereby giving more options in choosing feasible origin shifts.

For future work, we will test the robustness of our approach by taking subsets of maps of actual cities and simulating attacks. Other avenues of inquiry include a user in motion and a user specifying a cloaking region.

## Acknowledgment

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# Estimation of Network Jitter Using Delivery Instant Parameter of MPEG MMT Protocol

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***Abstract*—Recently, ISO MPEG has developed a new media transport technology called MPEG Media Transport (MMT) protocol for the next generation hybrid video delivery services over IP networks. In this paper, we propose an efficient estimation of network jitter using delivery instant parameter of MPEG MMT protocol.**

***Keywords-MPEG MMT; jitter estimation; video delivery over IP networks.***

## I. INTRODUCTION

ISO MPEG developed the MPEG-H standard suite (ISO/IEC 23008) for the delivery of audio-visual information compressed with high efficiency over a heterogeneous environment. The MPEG-H suite consists of three functional areas: High-Efficiency Video Coding (HEVC), 3D audio, and MPEG Media Transport (MMT) [1].

Maintaining timing relationships among packets in a single media stream or between packets from different media streams is an essential role of MMT. It is the function of the synchronization and de-jittering algorithms to re-adjust timing relationship between the MMT packets to assure synchronized playback [2]. Thus, delivery of time constrained MPEG media on time, according to their temporal requirements, is an important goal of MMT. For this purpose, MMT provides delivery instant parameter in its packet header to specify syntax and semantics of a timing model to be used by the delivery functions [3]. By using the delivery instant parameter, it is possible to estimate end-to-end transmission delay or network jitter. The total end-to-end delay should be kept constant for continuous decoding and playback at the receiver.

In this paper, we propose an efficient method to estimate the network jitter for predicting constant end-to-end delay and estimating appropriate buffering time using delivery instant parameter of MPEG MMT protocol.

The organization of this paper is as follows. In Section II, we describe conventional network jitter estimation method. Section III describes the proposed network jitter estimation method using MMT protocol. Concluding remarks and future works are given in Section IV.

## II. CONVENTIONAL NETWORK JITTER ESTIMATION METHOD

Internet Engineering Task Force (IETF) provides timestamps, such as Real-time Transport Protocol (RTP) timestamp [4], and Network Time Protocol (NTP) timestamp. Each RTP packet carries a 32 bits timestamp which reflects the sampling instant of the first byte in the data packet. For MPEG payloads, the sampling instant is derived from a 90 KHz clock. Besides RTP timestamps, an NTP timestamp is also transported in the RTCP Ssender Report (SR) packet.

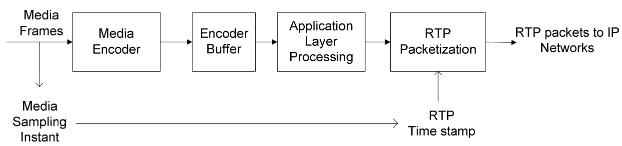


Figure 1. Media sampling instant used as an RTP timestamp in RTP packetization.

Figure 1 shows a media sampling instant used as an RTP timestamp in RTP packetization. As shown in Figure 1, if RTP packets are generated periodically, the nominal sampling instant as determined from the sampling clock is used as an RTP timestamp, not a reading of the system clock. In RTP, the inter-arrival jitter is defined to be the mean deviation of the difference in the packet spacing at the receiver compared to the sender for a pair of packets. In IETF RFC 3550 standard, the following method is used to estimate network transmission jitter. If $Si$ is the RTP timestamp from packet $i$, and $Ri$ is the time of arrival in RTP timestamp units for packet $i$, then for two packets $i$ and $j$, the difference in packet spacing at the receiver is expressed as

$$D(i,j) = (Rj - Ri) - (Sj - Si) = (Rj - Sj) - (Ri - Si)\,. \quad (1)$$

The inter-arrival jitter is calculated continuously as each data packet *i* is received according to the following formula

$$J(i) = J(i-1) + (|D(i-1,i)| - J(i-1))/16 . \quad (2)$$

Because the jitter calculation shown in (2) is based on the RTP timestamp, any variation in the delay between the sampling instant and the time the packet is actually transmitted will affect the resulting jitter that is calculated. Such a variation in delay would occur for video encodings because the timestamp is the same for all the packets of one video frame but those packets are not all transmitted at the same time. Thus, the variation in delay until transmission could reduce the accuracy of the jitter calculation as a measure of the behavior of the network by itself.

## III. Proposed Network Jitter Estimation Method Using MMT Protocol

Preservation of timing relationships among packets in a single MMTP packet flow or between packets from different MMTP packet flows is an important feature of MMT. In the conventional method, if the time gap between the sampling instant and the transmission instant could be always kept as a constant, there would be no problem in the accuracy of the calculated jitter. However, the problem could occur in transmitting a video frame with huge resolution, such as 4K/8K UHD video, as an example.

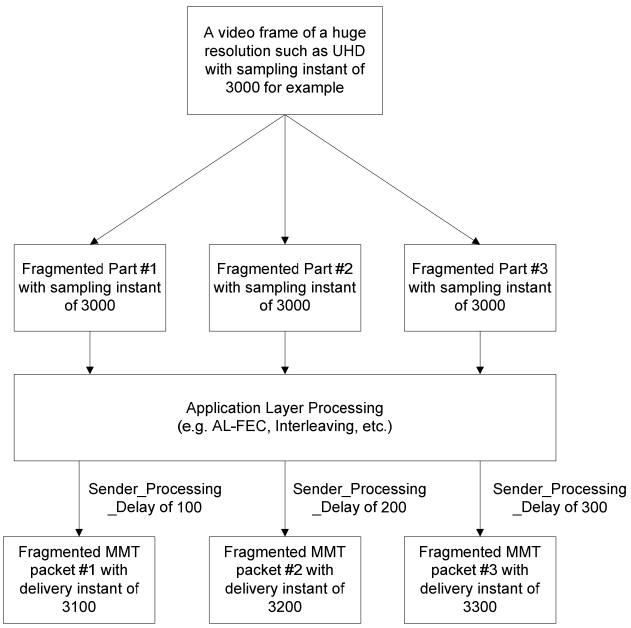


Figure 2. A video frame of huge resolution is fragmented into three different delivery packets, each with different delivery time.

Due to its big size of 4K/8K UHD video frame, the compressed bitstream may need to be fragmented into several delivery packets before transmission as shown in Figure 2.

Although the three fragmented packets are originated from the same video frame with the same sampling instant, they are transmitted at different delivery time due to additional application layer processing such as Applicatoin Layer Forward Error Correction (AL-FEC) and Interleaving. Thus, by assigning the delivery instants to MMT packets as shown in Figure 3, we would be able to achieve accurate estimation of inter-arrival jitter in MMT service. Instead of using (1), we can employ the following equation to obtain the difference in packet spacing for two MMT packets *i* and *j* at the receiver:

$$D_{MMT}(i,j) = (T_{A,j} - T_{A,i}) - (T_{D,j} - T_{D,i}) = (T_{A,j} - T_{D,j}) - (T_{A,i} - T_{D,i}) . \quad (3)$$

In (3), $T_{D,i}$ and $T_{D,j}$ denote the time instant of delivering two MMT packets *i* and *j*, respectively. $T_{A,i}$ is defined as the time of MMT packet arrival in D-layer timestamp units (may be in NTP timestamp format) for MMT packet *i*. The inter-arrival jitter is calculated continuously as each MMT packet *i* is received according to the following formula:

$$J_{MMT}(i) = J_{MMT}(i-1) + (|D_{MMT}(i-1,i)| - J_{MMT}(i-1))/16 . \quad (4)$$

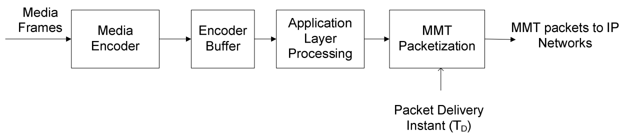


Figure 3. Delivery instant information to be included in the MMT packet header in D-layer packetization.

The proposed algorithm described in Section III has been included in the International Standard document of MMT [5]. We will focus our attention on the test and implementation of the proposed algoirhtm using MMT protocol to verify the performance of the proposed network jitter estimation method in a real video delivery environments over IP networks.

## IV. Conclusion and Future Work

In this paper, we proposed an efficient method to achieve accurate estimation of inter-arrival jitter using delivery instant parameter of MPEG MMT at the receiver side. To achieve the accurate estimation of network jitter, the sender side needs to transmit delivery instant information based on the MMT timing model to the receiver side. As our future work, we are going to verify the performance of the proposed network jitter estimation method by implementing the algorithm in a real video delivery service over IP networks.

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