Mobile, Personal Data Offloading to Public Transport Vehicles

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ABSTRACT

This paper proposes data offloading to public transport vehicles for alleviating heavy traffic load over mobile networks and efficiently delivering delay-tolerant and large data objects. With the proliferation of smart mobile devices, mobile data traffic is increasing at an unprecedented rate, and the increase then weighs heavily on mobile networks. To relieve the traffic load, data offloading through WiFi and Femtocell has recently attracted considerable attention. They, however, have some difficulties to offload high-volume data objects, such as video data, because of the limitations of their transmission speeds and user mobility. This paper explores offloading delay-tolerant and large data objects to public transport vehicles by using high-speed short-range wireless communication.

Keywords: Data offloading, Public transport vehicles, large data object, Delay tolerance, High-speed short-range wireless communication

1 INTRODUCTION

With the widespread use of advanced functionality and high performance smart mobile devices, the smart mobile device is projected to become the principal communication device for the end user. The user will deploy diverse applications on the smart mobile device, producing and storing text, photos and videos. In reference [1], Cisco Systems, Inc. estimates that global mobile data traffic in 2012 will grow 2.1-fold of 2011 (i.e., 597 petabytes per month in 2011 and 1,252 petabytes per month in 2012), and the traffic is also forecasted to increase 18-fold between 2011 and 2016 (i.e., up to 10,804 petabytes per month in 2016). Additionally, in 2011, mobile video traffic increased to 52 % of the whole mobile data traffic. Figure 1 shows that mobile video data traffic will occupy 70 % in 2016. Further, users will demand more high-definition content because devices with higher resolutions are emerging. As a consequence, file sizes will be growing.

At present, in a densely populated area like Tokyo, the increase of smart mobile devices and mobile data traffic is causing heavy traffic load over mobile networks, and consequently it is difficult to provide the communication quality that users desire. To avoid the degradation of

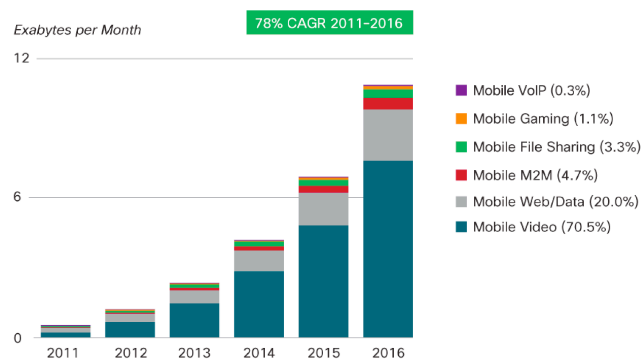


Figure 1: Global mobile data traffic forecast (Source: Reference [1]).

communication quality, wireless communication service providers are advancing the extension of wireless communication infrastructure such as Long Term Evolution (LTE) and WiMAX. Reference [1] also estimates that mobile network connection speeds (i.e., 315 kbps in 2011) will increase 9-fold by 2016 (i.e., 2.9 Mbps in 2016). Given such high traffic forecast (18-folds), we believe that merely extending wireless communication infrastructure is insufficient for alleviating traffic load over mobile networks. Meanwhile, as one of a number of measures to ease heavy traffic load, wireless communication service providers plan to introduce changes in data plans and regulation of communication. Unlimited data plans are being switched to tiered data plan. In terms of regulating communication rates, if a user traffic amount exceeds a permissible level during a certain time period, the user's connection speed is downgraded. Such undesired measures, however, make wireless communication less appealing.

It is difficult to solve the problem only by the extension of LTE, WiMAX, etc., because the origin of the problem is the limited wireless resources. Then, to efficiently make good use of other wireless resources, mobile data traffic is expected to be offloaded to wired networks via Femtocell [2] and WiFi. Femtocell, however, is not suitable for data offloading in terms of signal strength and frequency, because the main objective is to extend the wireless link for unreachable areas. In WiFi, an access point (AP) covers indoor communication such as a coffee shop since it is a small area. WiFi is not suitable for longer distance outdoor communication. Although the connection speed of WiFi is expected to be faster than that of cellular networks, the connection speed of WiFi might be degraded if many users connect to the same access point. Besides, references [3][4] showed the connection speed of WiFi is slower than that of cellular networks during movement.

As another approach for data offloading, some researchers consider delay tolerance to the extent that users and applications can accept [5][6]. Whenever users are communicating on a mobile network, they typically freely transmit irrespective of the effective connection speed that they can attain, and without tolerating any delays. However, there are some applications that are able to accept some delays. Applications that do not need real-time communication (e.g., e-mail, video data, and backup data) may improve the efficiency of data offloading by being late to start communication. Even if users try to send/receive non-real-time application data via cellular networks, users might not be able to achieve sufficient connection speed. Thus, users might be able to complete the communication in a short time, when they start the communication after finding a WiFi network. Also, reduction of communication time contributes to power saving.

As for large data objects such as video data and backup data, even with a WiFi network, the user may not be able to send/receive the large object in an acceptable time. For example, under an assumption that the connection speed of cellular network is 2.9 Mbps, it takes almost one and a half hours to download a 2-GByte video file[1]. If uploading, it might take more time. On the other hand, although the connection speed of WiFi is generally considered to be faster than that of a cellular network, it is difficult to always attain the best connection speed depending on signal strength and WiFi network congestion level. Consequently, as communication time becomes longer, users must also remain confined to a WiFi-enabled area.

This paper discusses the possibility of data offloading to public transport vehicles for sending/receiving large data objects that can accept some delay. In the proposed approach, we employ public transport vehicles, such as a bus or a train, as a communication medium between users and the Internet. A user sends a large data object to a public transport vehicle by using high-speed short-range wireless communication, and the public transport vehicle forwards the object to the Internet after carrying to its terminal. On the other hand, as for receiving a large data object, a public transport vehicle receives a user's data from the Internet, and delivers it to the location (e.g., a bus stop or station) where the user desires to receive it. After that, the user receives the large data object using high-speed short-range wireless communication. Since such public transport vehicles are closely related to users' daily life (e.g., commute), users have frequent access the reachable locations such as bus stops or train stations. A benefit of this approach is that the delivery time of the user's data can be estimated, because the public transport vehicles basically follow timetables. The paper proposes the basic design and performance for data offloading to public transport vehicles, and then considers technical issues for achieving it.

This paper is organized as follows. Section 2 surveys related work. Section 3 describes the basic design and performance for data offloading to public transport vehicles. Section 4 shows the technical issues for achieving it. Concluding remarks are presented in Section 5.

2 RELATED WORK

References [3][4] show experimental results for data offloading via WiFi. In reference [3], the authors measured the throughput of 3G network and WiFi network between Carnegie Mellon University and business district through walking and driving. The results showed that as for instantaneous throughput, WiFi networks are faster than 3G networks, while the average downloading throughput of 3G networks are faster than that of WiFi networks. On the other hand, in uploading throughput, a WiFi network is superior to a 3G network for instantaneous and average throughput, because the uploading throughput of a 3G network is basically slow. In reference [4], the authors measured the communication throughput of 3G networks and WiFi networks through driving in three cities: Amherst, Seattle, and San Francisco. The measurement results showed that a 3G network provides higher throughput in downloading and uploading than WiFi networks. From their results, we can see that users can obtain higher throughput on a 3G network during mobility, and on a WiFi network when stationary.

To efficiently improve data offloading, references [4][5] have studied data offloading for delay tolerant applications. Reference [4] proposed a data offloading method that a smart mobile device sends/receives data objects within user's tolerant delay by using WiFi as much as possible. The method makes a threshold for delay tolerance, and considers data size and expected throughput in WiFi areas where a user will visit. If a user cannot offload all data within the desired delay through WiFi networks, a user can use a 3G network to complete the data transfer within the delay period. In reference [5], the authors measured WiFi connectivity for about 100 iPhone users in Seoul, Korea. Based on the results, they then evaluated via simulation that the total bytes transferred through WiFi divided by the total bytes generated when a user accept delay. From the simulation results, in the case that 6 hours delay is accepted, the efficiency of the data offloading rose up to 87.5 %[2]. The

[1] A 10-minutes video file of Quick Time Motion Jpeg (1270 * 720, 30 fps) is assumed.

[2] If users make sure to offload data to WiFi network when both 3G and WiFi networks are available, the offloading efficiency is 64.7 % without tolerating any delays.

authors, however, note that the results depend on coverage area of WiFi network and user's mobility. Also, reference [6] proposed a data offloading method in which a smart mobile device offloads data to another device by a Store-Carry-Forward routing, like delay/disruption tolerant network (DTN) [7]. As described above, data offloading that considers acceptable delay for users and applications is becoming a new trend.

Some studies [8][9] proposed data offloading methods for power saving on smart mobile devices. In reference [8], authors investigated how the scanning of WiFi APs affects a smart mobile device's battery. Since the result shows that increasing the scanning interval can prolong battery life, they, a data offloading method that considers the scanning intervals is necessary to improve efficiency of data offloading. Reference [9] also showed that scanning APs drains the battery on a smart mobile device. The results show that we may save battery power when the scanning interval is longer. However, since it may be slow to find the next WiFi network, the connection period during movement may be reduced. Therefore, to efficiently offload data to WiFi networks, AP scanning intervals and battery consumption should be carefully considered. Additionally, to efficiently make a connection to WiFi networks, reference [10] proposed connectivity forecasts. The method forecasts WiFi networks that a user will visit based on knowledge of the user's daily movement. Although various approaches have been studied for data offloading to WiFi networks, to be feasible, it would be required to build a lot of WiFi networks. Besides, as APs increase in number, various issues such as deployment and radio interference would need to be resolved. Thus, to provide the communication quality that users desire, various system issues still remain to be addressed beyond the approaches above.

3 DATA OFFLOADING TO PUBLIC TRANSPORT VEHICLES

As discussed in Section 2, data offloading to WiFi networks will be able to somewhat alleviate mobile networks traffic overload. It is however insufficient for offloading large data objects such as video and backup data. This section proposes a strategy for data offloading to public transport vehicles, applicable to large data objects of delay tolerant applications. Section 3.1 describes requirements of data offloading. Section 3.2 explains how the proposed offloading works. In Section 3.3, the effectiveness of the data offloading is presented.

3.1 Requirements

For effective data offloading of large data objects, the following requirements should be satisfied:

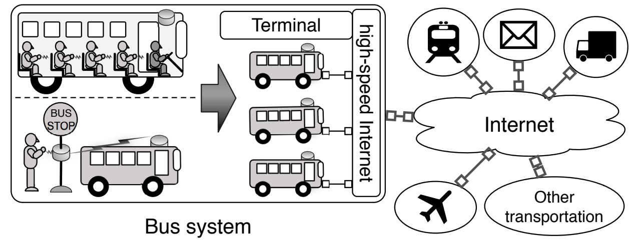


Figure 2: Data offloading to public transport vehicles.

(1) Easy access to reachable offloading spots, such as bus stops or train stations
(2) Fast and stable data transport
(3) Delivery within acceptable delay
(4) Limited impact on mobile device battery

First, a user needs to be able to easily access offloading spots without particular knowledge of such spots. In data offloading via WiFi networks, a user needs to search for WiFi networks by using a smart mobile device, because WiFi radio signal is invisible. Thus, such a task restricts user mobility. In our proposal, the user can visibly identify the offloading terminal.

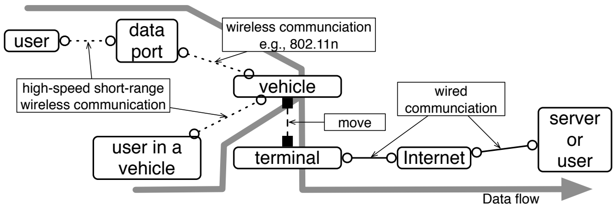
Secondly, to avoid restrictions on user mobility, fast and stable data transport is required. In WiFi networks, even if a user stays within the coverage area, the user may not always obtain the desired communication throughput because of weak signal strength or a congested AP. Also, since APs are deployed indoors, a user needs to stay indoor to obtain better communication quality. In some cases, although a user may be able to access an AP outdoor, in most such cases, communication quality is likely to be degraded. Consequently, the communication time is prolonged and also the user mobility is restricted. Therefore, fast and stable communication is required to alleviate the mobility restriction.

Thirdly, large data objects must be delivered to an addressee within acceptable delays for the user and the application. Hence, we need to design for the large data objects to be delivered within required delays.

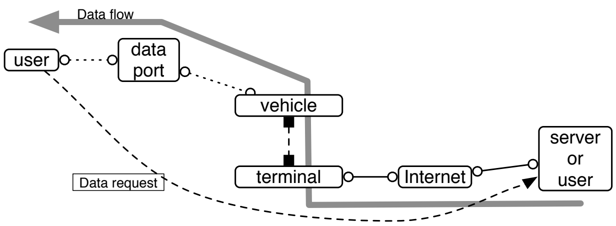
Lastly, since battery consumption severely impacts the number of contiguous hours a smart mobile device is operated, we need to save battery power as much as possible. In particular, AP scanning and long transmissions should be reduced .

3.2 Proposed data offloading scheme

This section proposes data offloading to public transport vehicles for delay-tolerant and large data objects. We first explain the overview of the data offloading strategy in Figure 2. We employ public transport vehicles such as regularly scheduled metro area buses, high-speed rails etc. We assume smart mobile devices equipped with a high-speed short-range wireless communication medium such as



(a) Uploaded data flow



(b) Downloaded data flow

Figure 3: Communication flows in the offloading system

TransferJet [11] or WiGig [12]. TransferJet aims to reach 560 Mb/s of communication speed, while WiGig aims to reach 7 Gb/s.

As an example, we envisage the following scenarios for data offloading to a bus system. Since data communication can be divided into two flows, uploading and downloading, we first introduce an uploading scenario. As illustrated in Figure 3(a), a user drops a large data object off into a data port at a bus stop that the user always frequents, or a user directly drops a large data object off into an electronic storage system on a bus. At a bus stop, as illustrated in Figure 4, after a user states an acceptable delay for their large data object, the user tries to “drop it off” into a data port deployed at the bus stop. If the data port estimates it can deliver the object within the delay acceptable to the user, the data port accepts the object for transport. Otherwise, the data port indicates its estimated delivery time, and the user then decides whether to “drop it off” or not. When a bus arrives at the bus stop, data objects in the data port are transferred to an electronic storage system on the bus via wireless communication media such as 802.11n or WiGig. Alternatively, on a bus, a user riding the bus can directly transfers their object to the electronic storage system on the bus via a terminal unit provided on the bus seat. The bus carries the forwarded data objects to a bus terminal. At the bus terminal, the bus offloads the data to the Internet through a high-speed connection like an optical fiber cable.

In a download scenario (see Figure 3(b)), a user requests a server to deliver a desired data object within an acceptable delay to a place where the user will go, e.g., a bus stop or a station. At this time, the server checks whether it can deliver the object within the stated delay bound, and then

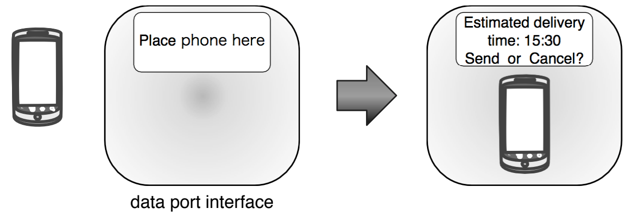


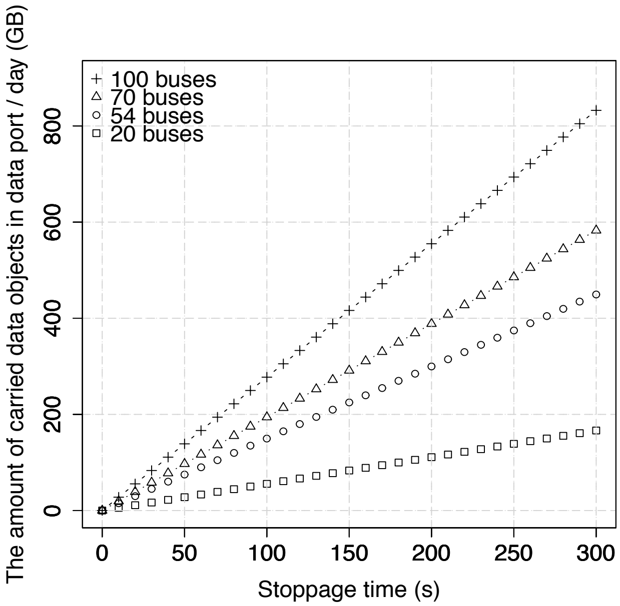
Figure 4: How to access to a data port

the server returns the result to the user, as a data port would do for an upload request. If the request is feasible, the server forwards the data object to a terminal for a vehicle that can deliver it to the requested place. A vehicle then picks it up at the terminal and drops it off into a data port at the requested place. After that, the user picks up their object from the data port whenever they arrive at the specified delivery location. We envisage the deployment of data ports at various locations encountered in daily life. Thus allowing users easy access to upload/download large data objects in a short time via a high-speed short-range wireless interface such as TransferJet.

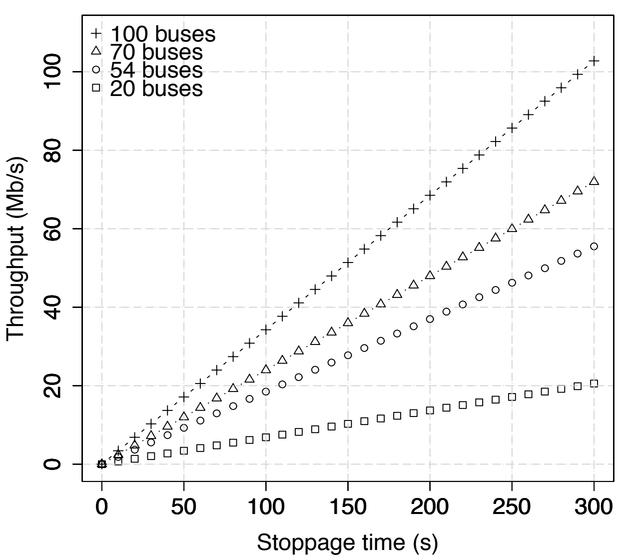
3.3 Capacity of the offloading system

Throughout this paper, we use a bus system as an example, but this concept is easily applicable to other transportation systems. We assume that a smart mobile device has an interface for high-speed short-range wireless communication such as WiGig or TransferJet. Likewise, data ports as well as buses employ WLAN (802.11n) and a high-speed short-range wireless communication. A high-speed short-range wireless communication is used for communication between the user and facilities (a data port or a bus), while 802.11n is employed for communication between a data port and a bus. We assume further that both the bus and the data port have very large but finite data storage capacities.

The effective transmission speed of 802.11n is assumed to be 222 Mb/s [5]. Our main emphasis is measuring the transmission performance for data objects in a data port at one bus stop, since the overall transmission performance practically depends on data transfers from a data port to the bus. Data objects that are picked up from/dropped off into a data port are restricted by the bus stoppage time at a bus station, according to a transit timetable. In other words, the transmission between a data port and a bus is the bottleneck in this system. The amount of data objects from/into a data port per day is calculated as follows: *The amount of data objects from/into a data port at one bus stop in a day* (MB) = (*Effective transmission throughput between a data port and a bus* (Mb/s) * *Stoppage time at a bus stop* (s) * *the number of buses in a day*) / 8. The throughput during service operation is calculated as follows: *Throughput*



(a) The amount of offloading data for operation time



(b) Effective throughput for operation time

Figure 5: Ideal data offloading performance at one bus stop

during service operation (Mb/s) = ((*The amount of data objects from/into a data port in a day* (MB)) * 8 / *Operation time* (s). Thus, the transmission performance highly depends on stoppage time at a bus stop and the number of buses in a day. Figure 4 shows the ideal transmission performance for data objects in a data port. Figure 4(a) shows the amount of data offloading during the operation time, while Figure 4(b) shows the throughput during service operation. When each bus stoppage time is 120 seconds, for a total of 54 buses, the offloading capacity of a data port is approximately 180 GB/day with an effective throughput of 22.2 Mb/s. Since the results depend only on data objects in a data port at one bus stop, we also need to account for the data objects from passengers. Moreover, if a bus system has 10 bus stops, the effective total throughput of the bus system is more than 222 Mb/s. Therefore, a public transportation system has significantly large potential for offloading large data objects.

4 TECHNICAL ISSUES

To efficiently offload large data objects by means other than WiFi and Femtocell, we proposed data offloading to public transport vehicles as another approach, and provided an architecture overview and a capacity calculation. To implement the proposed concept, the following issues should be resolved.

4.1 Smart mobile device issues

The smart mobile device needs a high-speed short-range wireless communication interfaces such as TransferJet or WiGig. Since some products with TransferJet have been already sold, the release of a smart mobile device with a TransferJet is expected in the near future. On the other hand, the Wireless Gigabit Alliance states that more are scheduled throughout 2012 with the first release of certified WiGig products set for early 2013 [12]. In the paper, although TransferJet and WiGig were assumed, we would also expect similar results even if 802.11n is used instead.

Another issue that needs more consideration is the interaction of users and data ports for user specification of their desired delay, and the required dialogue to negotiate, accept or reject the offload operation. Thus, we need to make a detailed design for an application that operates on smart mobile devices.

4.2 Data port and server issues

A data port and server need to indicate to a user whether the requested data can be delivered within an acceptable delay or not. For this, they need a delivery scheduling method according to timetables, the size of the requested data objects etc. The delivery scheduling method needs to consider some unpredictable delays and cancellations for public transport vehicles in particular. Finally, we need to consider saving electric power and consider the use of solar panel for data ports, which depending on location, may not be always able to secure electric power.

4.3 Communication issues

Since the data offloading method employs a data port at a bus stop and station as a destination, we need to enable a user to easily designate the place and to make a relationship between places and IP addresses.

In addition, since a smart mobile device has no end-to-end connection, i.e., device to device, in the data offloading, a Store-Carry-Forward manner needs to be studied to be applicable to the data offloading. Although a TCP connection has so far guaranteed reliable communication, it is difficult for a Store-Carry-Forward manner to ensure reliable communication. Then, to enable a user to confirm the delivery status, we need to design and implement a function that works in close cooperation with public transport vehicles. For example, when a vehicle drops off / picks up a data object, or the data object will be delayed and lost, the data offloading method will send a message to a user. Since lost data is a serious problem, intermediate vehicles may need to temporarily keep duplicated data. Furthermore, since a user cannot always receive the data at the requested place, a forwarding method is needed to freely transfer the data object to another place according to a user's request.

4.4 Security

Since data objects are delivered via various vehicles, it is important to make a secure delivery. In addition to data encryption, it is also necessary to make authentications between smart mobile devices and intermediate communication objects.

5 CONCLUSION

This paper explored large delay tolerant data objects offloading from mobile wireless networks to public transport vehicles. The method enables a user to send or receive a large data object to/from a data port via high-speed short-range wireless interface in a short time. Compared with offloading to WiFi, the proposed method would alleviate the restrictions on users mobility. Also, since it employs public transport vehicles, it would enable a user to easily access a port at a reachable location often encountered in the process of daily life. Another good feature of employing public transport vehicles is the ability to estimate a delivery schedule since the vehicles follow a fixed timetable. At present, although the data offloading method is at a concept level, resolving a few remaining issues would render the method an effective approach for alleviating traffic load on mobile networks.

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