A Sustainable Marriage of Telcos and Transp in the Era of Big Data: Are We Ready?

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Abstract. The emerging smart city paradigm e.g., intelligent transport, smart grid and participatory sensing etc. is to advance the quality, performance and experience of urban citizten services through greater connectivity. This paradigm needs to collect data from citizens, various devices and assets that could be monitored, processed and analysed for the city governers to make better decision and also more efficiently manage those assests and resources. While the telecommunication and Internet are progressively being over-burdened and congested by the growing data transmission demands. To keep expanding the telecommunications and Internet infrastructures to accomodate these intensive data demands is costly and also the associated energy consumptions and carbon emissions could at long last wind up genuinely hurting the environment. To face this issue in the coming era of big data, we envision it will be best to utilize the established urban transport and road infrastructure and existing daily massive vehicular trips, to complement traditional option for data transmission. After detailing the current state-of-the-art, we consider the main challenges that need to be faced. Moreover, we define the main pillars to integrate the telecommunications and transport infrastructures, and also a proposal for the future urban network architecture.

Keywords: Smart city · Intelligent transport · Energy consumption
Data offloading · D2D communication · Carbon footprints
Delay tolerant network

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1 Introduction

The emerging smart city (SC) paradigm needs to collect data from citizens, various devices and assets that could be monitored, processed and analysed for the city governers to make better decision and also more efficiently manage those assests and resources. Cisco predicts that a SC having a population of 1 million could generate 180 million GB data per day or 42.3 ZB/month [1]. One of the fundamental issues of SC is the accumulation of big data and information generated by different data sources remotely and to transfer this data to some predefined data centers. These data sources in the SC can be interconnected through various transmission media. However, the idea of "smart" leads basically the efficiently and wisely utilization of infrastructures and resources. These sources may include Smart Grid (SG) sensors, environmental monitoring systems, Smart health monitoring systems, field sensors, video surveillance stations. For example in SG, smart devices and meters are installed throughout the city for management, controll, and monitoring. These SG devices generate a tremendous amount of the data, which needs to be transmitted to utility control centers in order to manage the SG services. It is predicted that this SG data yields a 8000-fold increase in daily data volume, and in 2015 it is augmented to over 75200 TB [2]. Figure 1 [3] shows Cisco's forecast in 2017 for the mobile traffic Exabyte per month till 2021, and the projected data traffic almost sevenfold in 5 years' time. Global mobile data traffic grew 74% in 2015. It is 4000-fold vs. past 10 years, 400-million-fold vs. 15 years. The total Internet traffic has experienced a dramatic growth in the past 2 decades and is still growing very fast. Data rates of 5G are five times faster than the 4G whereas the mobile data growth is sevenfold in 2021 [4]. Hence data offloading is a promising solution to meet this exponential growth of mobile data as shown in Fig. 1.

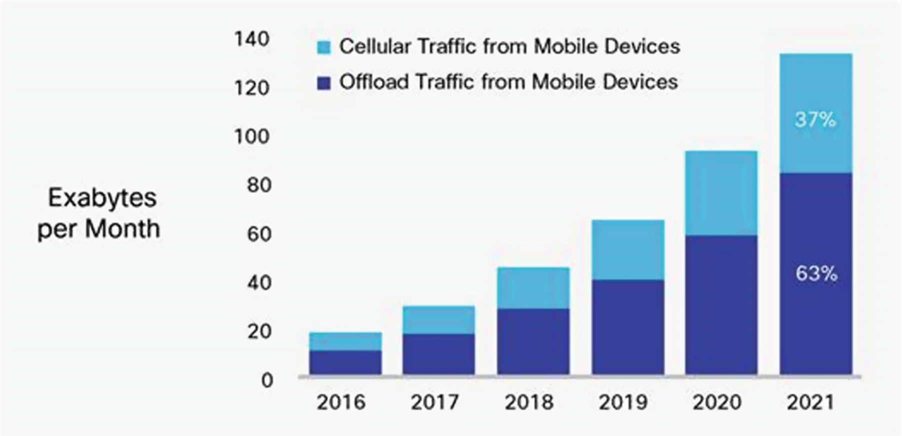

Fig. 1. Offloading needs of total mobile data traffic [3].

The rest of the paper is organized as follows. In Sect. 2 we review the relevant literature in delay tolerant network and D2D communications. In Sect. 3 our detailed vision is reported. In Sect. 4 we define our proposed network architecture in detail. Finally, the paper is concluded in Sect. 5.

2 Related Work

We address the issues of Delay Tolerant Network (DTN) [5] and particularly one of its variant, the Assisted Delay Tolerant Network (ADTN). In ADTN, we use different data carriers like cars, buses, trains, airplanes, etc. for store-carry-forwarding the data. These data carriers having radio interfaces, processing power and storage capacity act like moving routers and enhance the network capacity.

In [6], authors use throw boxes having radio communication, processing, and storage capabilities, to enhance the network capacity by deploying these boxes at planned positions in the network. Instead of using fixed nodes, some other approaches uses the moving nodes to increase the network throughput by adding some randomness through node mobility. In [7], random moving data MULEs (Mobile Ubiquitous LAN Extensions) are used to collect data opportunistically from data sources to data processing centers. Instead of using randomness, authors exploit the use of non-random movement of scheduled vehicles to transfer data from some selected sources on their pre-defined routes to the final destinations.

The above-defined literature enhances the network capacity in a small geographical area. Whereas in [8], to transport data on the large geographical area the authors propose the use of mobile gadgets of passengers, waiting for their scheduled flights. Data is loaded onto the mobile gadgets of the passengers with respect to their destinations, while they are sitting in the waiting hall to wait for their scheduled flights. In this study, results show that data delivery by using scheduled flights, when data transmission is equal to three DVDs, give equal throughput as a single TCP connection.

Being inspired by the work of Marincic and Foster [9] and Baron et al. [10], we are proposing an energy efficient data dissemination framework in a smart city. Marincic presented different scenarios to transport the data as atoms by using different types of vehicles and calculated the energy consumptions. Baron uses electronic vehicles and annual average daily traffic count for big data offloading on the road network of France. In our work, we enhance their data models by considering the advantage of D2D communications.

We efficiently utilize the vehicle volume on the road and D2D communication of future smart cars with roadside units, under the control of cellular networks, to transport big data from various data sources of SC to their corresponding data centers. Instead of using separate storage media, these smart cars will have their own storage, processing, and radio communication modules. These modules contain Wi-Fi, GPS, as well as cellular interfaces. In this paper, we propose a framework that offloads the data from congested networks and reduces the delay, energy cost, and carbon emissions through these smart vehicles by using their routine rides.

3 Our Vision

We first define the main pillars which, we believe, are essential for the design and management of proposed system, for delay tolrent data offloading in SC environment. In the following we sketch the proposed architecture.

3.1 Main Pillars

D2D Communication: To address the challenges of cellular data crises, a promising solution, device-to-device (D2D) communication has been suggested for next generation cellular networks. In D2D communication, mobile devices in wireless range can communicate with each other without traversing through the base station of cellular network or through the cellular backhaul. By exploiting the vicinity of mobile devices and direct communication, D2D data transmission can enhance the throughput, reduce the communication delay of mobile devices and it can enhance overall spectrum utilization, network throughput and performance [11]. Because of different advantages of D2D communication, proximate communication is appropriate for many user cases and it can introduced different peer-to-peer and location based services and applications.

A sound literature of D2D transmission is available, in this section we discuss the research issues of D2D communication and some existing solutions. In [12], multi-hop communication was proposed by using D2D communication in cellular networks. D2D transmission is analogous to ad hoc networks, the main difference is it often includes cellular network for controlling. A common classification of D2D communication is explained in literature [13]. With respect to spectrum utilization, D2D communication is divided into two strategies: (i) Inband D2D communication and (ii) Outband D2D communication. In first strategy, same energy spectrum band as of cellular communication is used for D2D communication, whereas in second strategy, to avoid the signal interference from cellular networks, some other bands like Wi-Fi, Blue Tooth, Wi-Fi Direct are used [14]. It is to be noted that, in outband D2D transmission, eNodeB BS can has different level of control over D2D transmissions such as connection establishment and neighbor discovery, this control can be managed by control channels of cellular networks. Otherwise D2D data transmissions work in self-governing mode. On the basis of spectrum resource utilization, Inband D2D data transmissions can be further characterized into two categories. If same spectrum resources as of cellular communications are used for D2D communication then it is called underlay D2D data transmission and if resources are reserved used for D2D communication from cellular spectrum band then it is called overlay D2D transmission [15].

Opportunistic Communication: When a number of users request for same contents in a given area, service provider governs the communication as an in charge and transferred the requested contents to the base station, and base station forwarded these contents to those users. These requested contents can be delivered to users by using three different approaches. In first case, the base station forward the requested contents directly to each user. In second case some of the target users are selected by the base station, it forward the data to the target users, and they disseminate the data among their peer users. Where as in third case, target users may store the requested contents and delivered to peer users when they are in their wireless range. If the selected users don't meet the timelines to transfer data, then cellular base station are responsible for deriving data to each of data-undelivered-subscriber. The latter case is referred as an opportunistic communication in [16]. Opportunistic communication also reduce the load on cellular base station that's why it can also be counted as a data offloading scheme. Target and peer user selection have main importance in opportunistic data offloading, these are explained here in more detail.

Target Carrier Selection: In content delivery networks there are several number of distributed server instead of a single server. These distributed servers store the more popular contents in their caches which are the most periodically requested contents by the users from main server. Now, it is not necessary for all users to get data from main server, they can get data from their nearby distributed server, hence the main server can remain uncongested. The same idea is implemented in opportunistic data communication in which target users cache the most popular contents in their cache and behave like distributed servers as in content delivery networks. In [17], a solution for target user selection is formulated and named as Mobile Social Network (MoSoNet). The users who already received the data from content delivering servers, or stored the contents that are requested by some other users, can be selected as a target user and can disseminate data to the other peer users who are selected as receivers in opportunistic social network.

In opportunistic networks, it is an important question that who is most suitable user as a target user among all users in network. In [18], one of the criteria is social importance of a user and it is defined as a number of peer users connected to that user. However, this not sufficient for selecting a user as a target user because it is possible that peer users are not interested in the contents that are stored by that users. Hence, another perimeter is defined as number of interested peer users in network for the selection of target user. Therefore, it is a trade-off between two these two factors for decision making over the selection of target user.

In another point of view, the problem of target user selection can also be formulated as an optimization problem having an objective of maximizing the number of peer users (number of content-delivered users) in a required time period so that load on the base station can be reduced. Different methods are defined in [17]. For an already defined number of selected users, in an approach of greedy algorithm, a set of target users are selected that maximizes the number of peer users or content-delivered users. As it can be considered that, greedy algorithm doesn't consider the location/time correlation and statistical consistency of user's daily presence. On the other hand in heuristic algorithms, this consistency is considered at an initial stage of target user selection. For example, consider a company whose employees remain present at its location at almost the same time during each working day of the week. In such a scenario, heuristic algorithm selects initial target user set same as before instead of defining the new set every day. Finally, initial target user selection set is picked up completely in a random way from all users. Simulation results of [17] showed that all these selection algorithm mitigated the traffic load on cellular network as compared to the scenario where data is delivered to each user by base stations themselves.

Peer User Selection: Peer users are those ones that accept the data contents directly from the selected target users. Data contents are transferred from base station to selected target users, and they can transfer these contents to the peer users in their wireless range via Bluetooth or Wi-Fi, by using an application like Haggle [18]. They can also disseminate the contents to their peers via some cellular resources in their social friend network like Twitter or Face book as mentioned before in Mobile Social Network (MoSoNet) [17].

D2D and Opportunistic Based Vehicular Networks: Due to the advantages of opportunistic and D2D technology, it is suitable for many vehicular related use cases, and can enable peer-to-peer and location based application and services. For instance, considering the enormous number of connected smart cars (connected cars in 2021 [1]), software update of smart car can put a noteworthy load on the cellular infrastructure, and cost a lot of money for car owners. Thus, the software update can be downloaded by some selected vehicles and then it can be transferred to other vehicles by opportunistic and D2D transmission. In this process, target vehicles can be selected by cellular network by applying some efficient algorithms and allocate appropriate resources to reduce the interference, optimize the performance and fulfill different QoS requirements. In this way, most of the cellular load and data traffic can be offloaded to V-D2D communication, and thus cost, energy and much of the cellular bandwidth can be saved. Furthermore, software update does not require the real time communication, it can compromise on some delays, in such cases the vehicular delay tolerant network (VDTN) can be employed to forward the software update package in a store-carry-forward manners which can further save the cost, energy and offload the cellular traffic. Audio/video streaming and gaming are some other type of data services among vehicular users such as social network in the vehicular proximity [19]. Generally, such types of applications are maintained by Wi-Fi direct, LTE-direct or DSRC communications, because of long device paring time and collisions they may not satisfy the proper requirements. V-D2D and opportunistic communication can support such type of services in a better way due to the use of cellular links for control channels. Cellular-control may provide connection setup within short delay time and batter resource allocation.

There are numerous research works that consider the problems of applying D2D communications in vehicular ad hoc networks. In [20], Cheng et al. investigate the validity of D2D communication for intelligent transportation systems (ITS) by applying spatial distribution of high mobility vehicles and on different channel characteristics. Simulation study showed that among all other D2D techniques, D2D-underlay got highest efficiency in spectrum utilization and transmission rate increases with decrease in distance of vehicles. Moreover, it is observed that with gradual increase in link density of V-D2D the average spectral efficiency first begins with growth then gradually declines, because when V-D2D link density increases then the network will get more severe interference. In [21], Sun et al. formulated a resource allocation strategy for cellular user equipment's (CUEs) and vehicular user equipment's (VUEs), to exploit the CUEs sum rate while assurance the strict delay reliability and consistency requirements of VUEs' services.

Business Insider (BI) intelligence research, predicts in 2021 for 82% of all cars will be shipped as connected cars [1]. These connected smart cars will have storage capacity, cellular, global positioning system (GPS), and wireless interfaces. If we consider Auckland city as a SC, it has 0.72 per capita vehicles in 2015 and this value is going to increase by each year as forecasted by the ministry of transport New Zealand. It predicts that the big volume of connected vehicles can produce a big bandwidth on the road according to our proposed system.

4 Proposed Network Architecture

We propose an opportunistic D2D based vehicular network data delivery architecture that utilizes vehicles (and also their existing trips), roadside networks, and D2D communications to assist to deliver those delay tolerantable data from different data sources to control centers. Data can be forwarded to and carried by vehicles and uploaded to data centers through SRU, instead of being transmitted through the cellular networks.

To demonstrate the key concepts, here we provide a smart-health service system model in Auckland city, New Zealand (Fig. 2) and its associated network architecture (Fig. 3). The cellular network coverage is ubiquitously available in the entire city and vehicles move around the city on various roads. The participating vehicles in this proposed architecture have been enabled with a dual mode, they can form an opportunistic network with roadside units and can be connected to the cellular network. The data forwarding mode selection algorithm will be placed in the central controller (CC) at the base station (BS). CC is to govern the overall communications between data sources and destinations via VDTN by using D2D communication. Whenever a data source wants to send data, it sends data request packet to CC by using cellular control signals. CC decides the most suitable option to transfer data via Internet or via VDTN by using the information of delay tolerant indicator (associated with data demand), available vehicle volume on the road, vehicle's trajectory history, and minimum energy cost. On the basis of these optimization results, CC decides, if core network is more suitable for the given request then the CC directs the source to

Fig. 2. Proposed system overview.

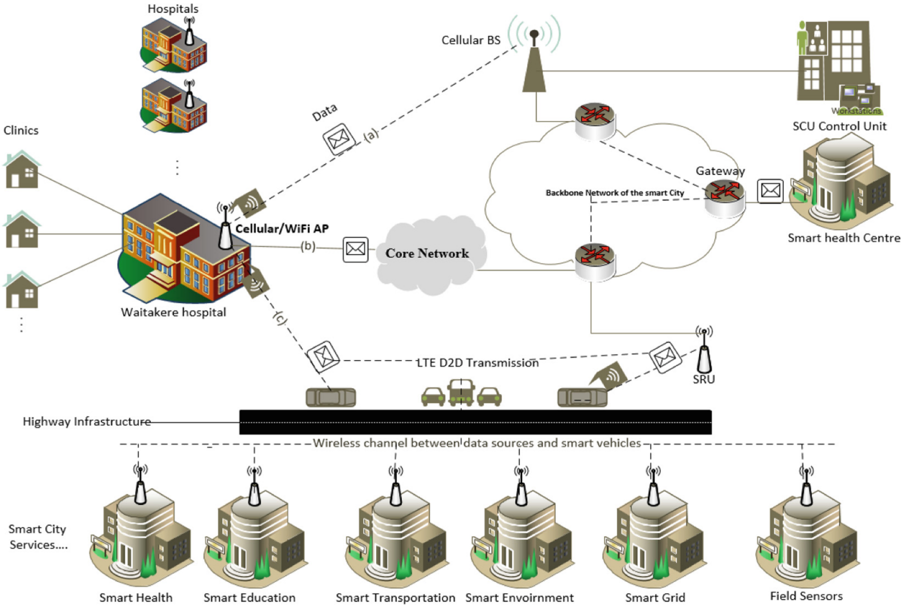

Fig. 3. Proposed system overview: data aggregation from various data sources to the central control units for storage and analysis.

choose an option (a) or (b) as shown in Fig. 3, else data can be forwarded by the vehicular network using the option (c). For this data transfer assignment, CC finds the appropriate vehicles on the basis of their trajectory history and directs the source to forward data to these vehicles one by one.

On the receiver side whenever a vehicle carrying data encounters with a smart city roadside unit (SRU), it uploads the data to the local network of the receiver by using that SRU. The receiver sends an acknowledgment to CC via cellular control signals after receiving a data bundle from a vehicle. In this paper we are more focused on the overall network architecture, while the analytical models and numerical validation on this proposed network architecture could be found in our recent work [1].

5 Conclusion

In this paper, we propose a network architecture for delivering the big data in smart city by using the existing transport infrastructure. It could best accommodate those massive and delay tolerant-able data transmission demands by utilizing efficiently the existing vehicles' mobility in the urban areas. Moreover, it could release the congestions in the wireless and wired networks, as well as reduce the energy consumption and carbon emissions. The automatic selection algorithm (i.e., selection of end-to-end data delivery path among wired, wireless or vehicular networks) for optimal data dissemination is to be discussed. In addition, the more complex mobility models and numerical validation studies are also needed in the future work.

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