Mobile Data offloading Techniques Using Licenced and Un-licenced Frequency Band: A Comprehensive Survey

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Abstract

In information communication technologies, new services demand from users, cost reduction constraints and traffic growth, and advancements in technologies (smart devices) are the main driving factors that cause network architecture modifications and evaluations. Data offloading is one of the anticipated architectures and it is defined as the delivery of user data to the receiver, base station (BS) or data centre by using different access technologies. Above mentioned three driving factors can also be reflected as strong drivers for the design and evaluation of data offloading techniques. In this proposed work, we review the topic of mobile data offloading and comprehensively survey the different methods of data offloading. We classify these methodologies in terms of their frequency band usage i.e. licensed or unlicensed and some of the techniques are also discussed in terms of media optimization. Finally, we proposed a system of data offloading by using a vehicular network and ended the survey and compared our work with the existing techniques.

Keywords: Data offloading, Vehicular Networks, Big Data, Base Stations, Control Centres.

Introduction

During the previous fifteen years, data traffic has been increasing exponentially with the invention of tablets, cell phones, smart devices and different bandwidth-hungry applications. This steady growth in data traffic has created a serious problem for mobile operators, which overloaded the core and access networks of their mobile network infrastructure. Shortly, there exists no possibility to reduce the impact of this problem but instead of intensifying since data traffic is predicted to raise more rapidly to a 92% higher yearly rate, it yields no relief to the already existing problem. Fig.1 (Index) below is Cisco's prediction in 2016 for the traffic Exa Byte per month till 2021, which shows that mobile data traffic will be nearly sevenfold trendy the next 5 years(CISCO, 2017).

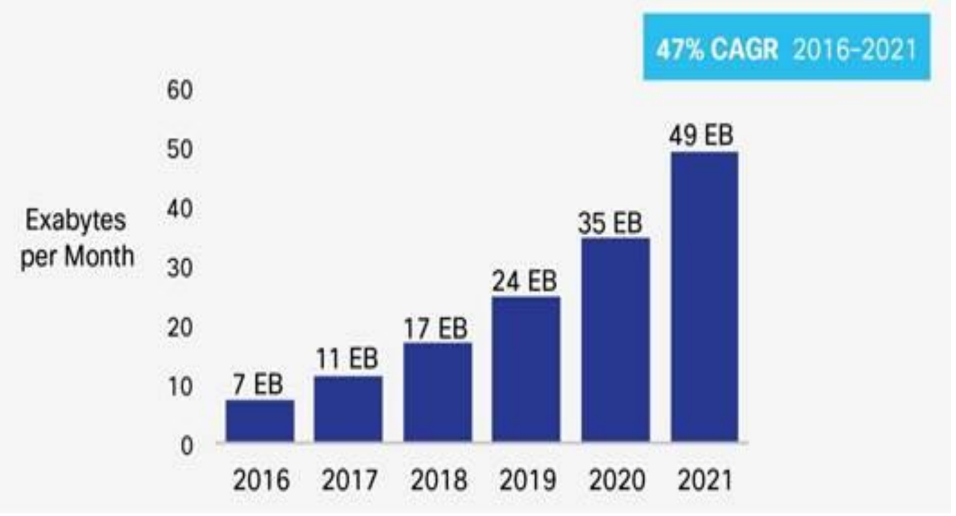

Figure 1: Cisco Predictions about Mobile Data Traffic Exa Bytes/Month (CISCO, 2017)

High demands for resource-intensive and bandwidth-hungry applications like video streaming such as in Dailymotion and YouTube become the main reason for this evaluation in mobile networks. This rapid evolution in mobile data traffic puts a big pressure on network operators to manage then evaluate their valuable network assets and resources in a improved and extra effective way (A. Handa). Infect, operators are not only suffering from the problem of capacity crisis but also some other challenges like the overload in the radio spectrum, declining average revenue per user (ARPU), non-optimal services data traffic path, costly data traffic of inter-autonomous Systems (AS) and the suffering of 3GPP outdoor coverage into indoor penetration, are also the concerns that must be compacted by the mobile operator (H. Ali et al., 2022). Although there exist several possible solutions to these problems these are not fully satisfactory solutions (Choi, Ji, Park, Kim, & Silvester, 2011), therefore in this paper, my focus is to survey one of the specific categories of the solutions that are defined as mobile data offloading(Lei, Zhong, Lin, & Shen, 2012).

The main impression behind the mobile data traffic offloading is to reduce the load or clear the overloaded, expensive and congested links like radio access networks (2G, 3G, 4G and 5G) and the core network by forwarding all or a part of mobile data to a cost-effective and alternate path(A. Handa), or by facilitating the data communication directly between the nearby user's equipment's via (D2D) Device to Device solution bypassing the (BS) Base Station(Lei et al., 2012) (Ahmad, Cherif, et al., 2022). 3GPP standardized several alternate solutions (I-WLAN) Internetworking Wireless Local Area Network, which integrates MPCN with a non-3GPP access WiFi Network(""3GPP system to Wireless Local Area Network (WLAN) interworking;System description," Sophia-Antipolis, France, 3GPP TS

23.234 v8.0.0 Release 8, 2011.,"). As WiFi works on the ISM band which is a license-free band it reduces the cost of data delivery and the use of WiFi link rather than 3GPP radio link access permits data offloading from traditional and expensive RAN of the mobile operator. With the cheap cost of WiFi communication, we have to face the different challenges of service mobility and managing secession continuity(Vaughan-Nichols, 2003),(Yan, Zhang, Zhou, Zhang, & You, 2010). Another way at the RAN level is also using microcells to compensate for the macro cell area coverage. Micro cells are integrated into MPCN by some fixed line like a digital subscriber line (DSL) that also reduces the data load at RAN ("“UTRAN architecture for 3G Home Node B (HNB); Stage 2,” Sophia-Antipolis, France, 3GPP TS 25.467 v10.4.0 Release 10, Dec. 2011.,") (Ishfaq et al., 2022). Micro or Femtocell BSs are 3GPP companionable equipment which supports QoS and reduces interoperability problems. Moreover, at the same time, the use of small cells creates the problem of interference that must be properly managed(Claussen, 2007).

At the core level, different offloading solutions are implemented by introducing local gateways near subscribers. It can be managed by using standard functions of 3GPP such Selective IP Traffic Offload (SIPTO) and as Local IP Access (LIPA) ("“Local IP access and selected IP traffic offload (LIPA-SIPTO),” Sophia-Antipolis, France, 3GPP TR 23.829 v10.3.0 Release 10, Sep. 2010.,") (Ahmad, Manzoor, et al., 2022).

Another solution, like caching the popular content near to end-user, is another a promising solution. Infect, caching content locally allows the data offloading of traditional expensive then congested links between subscribers and far-end servers. Furthermore, local content caching allows to replicate of some popular data contents inside the domain of the operator close to the end user's access. This solution also reduces the cost of inter-autonomous System (AS) mobile data between the Internet and MPCN (Rabinovich & Spatscheck, 2003).

The main concerns of the operators is to increase the performance of their mobile network by increasing the capacity of networks or by proficiently employing the prevailing network resources. To manage the explosion of data traffic, the other exclusive resolution is to uplift the standing mobile networks to the new generation mobile networks. One more exclusive solution is to improve the mobile network capacity by growing the number of Base Stations. But the problematic with these solutions is that it need huge volume of operational expense (OPEX) and capital expenditure (CAPEX)(He, Chen, Ge, & Guizani, 2016). The small amount of scarce licenced spectrum also hinders mobile network evaluation. Regulating authorities allow to usage of only a limited allocated part of the limited spectrum to mobile operators, which is very affluent. In this case the subscribers have to utilize the allocated wireless resources. Applying more data traffic on these limited spectrum resources over a firm limit will create service degradation and excavation the quality of experience (QoS) considered by the customers. During peak hours in congested urban areas, subscribers also experience delays, network outages, and low throughput because of overloading and congestion at the RAN level(Taylor, 2012). This problem concerns mainly the mobile network operators since they have to trade-off business profitability with customer gratification, the trend shows towards nearly flat-rate models. Infect, the exponential growth in data traffic flowing in the mobile networks does not create sufficient profit to be allocated to upgrade existing RANs. This creates a revenue gap defined by Mölleryd et al (Mölleryd, Markendahl, Werding, & Mäkitalo, 2010). These factors create interest in different resolutions to decrease the pressure of data traffic on the mobile cellular RAN instead of the upgradation of mobile networks (Naseer, Liu, Sarkar, Shafiq, & Choi, 2021).

The motivation in this work is the prediction of CISCO about data offloading. As shown in Figure 2, even in the presence of 5G in 2021 we have to offload 63% of mobile data by using some alternate solutions(CISCO, 2017).

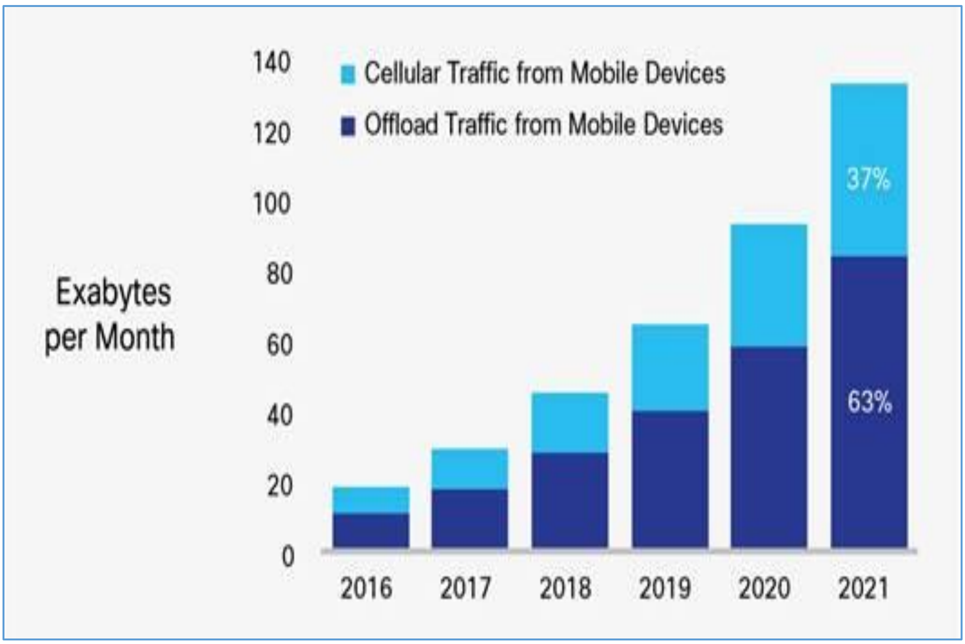

Figure 2: Mobile Data Traffic and Offload Traffic, 2021(CISCO, 2017)

The paper is organized in 6 parts, in 1st section we introduce the data offloading. In 2nd section we explain different data offloading techniques by using licenced and un-licenced frequency. In 3rd part different media optimization techniques are discussed used in data offloading. In 4th part we reveal an introduction of our system proposed in our previous paper (Naseer, 2021). In 5th section, we compared different techniques with our proposed system. Finally, the paper is concluded in 6th section.

Different Mobile Data Offloading Techniques

We divide the data offloading techniques into three approaches based on the use of frequency spectrum band resources. Some of the approaches use the licenced frequency and pay cost while some others use licenced free frequency. On the other hand, some techniques that get the advantages of both bands licenced and unlicensed frequency spectrum are called hybrid techniques. These categories are explained as follows.

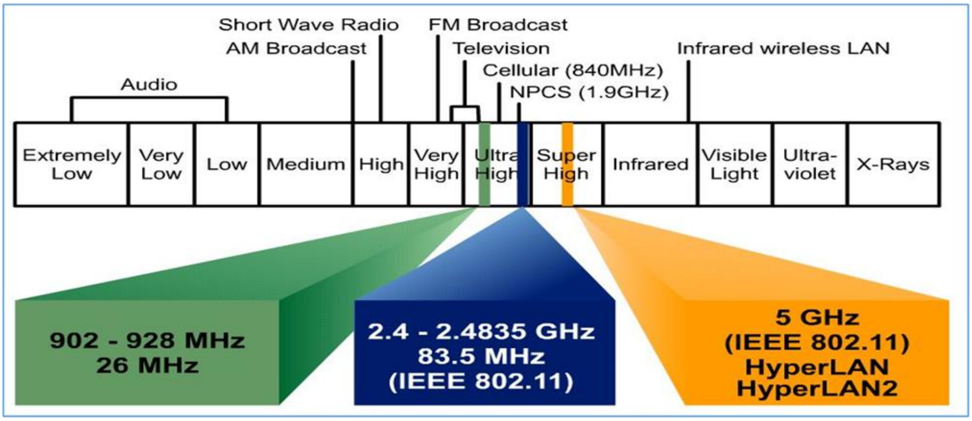

Figure 2: Energy Spectrum Band(Engelen, 2013)

1.1 Data Offloading by Un-licensed Frequency Spectrum

The ISM band is also called unlicensed or licence-free frequency in the energy spectrum band as shown in the figure. Any equipment having a suitable transmitter and receiver can use this band without having any reservations in this frequency range. Nevertheless, to use this frequency range a device must have to follow certain rules and regulations like restrictions on maximum signal power for data transmission(Engelen, 2013). IEEE 802.15 standards like Wireless HART, Blue tooth, ISA 100.11a and ZigBee use a frequency range of 2.4 GHz also some WLAN IEEE standards 802.11 family uses 2.4, and 5.8 GHz spectrum range of the ISM band (Naseer et al., 2018).

During the peak hours when a lot of users are using cellular networks, we use these bands to offload data from congested and costly links of networks to diminish the congestion on these links. Recently, the integration of Cellular Networks and Wifi got the consideration of researchers for cellular mobile data offloading (Naseer & Chaudhry, 2011).

2.1.1 WiFi Offloading

Wireless Fidelity is abbreviated as WiFi, IEEE 802.11 is a WiFi standard that provides wireless connectivity. The core usage of this technique is to access

broadband services in an indoor environment. WiFi delivers higher throughput with limited coverage and mobility as likened to other traditional wireless technologies alike Long Term Evolution, High-Speed Packet Access, WiMax, and Universal Mobile Telecommunications. Currently, WiFi is gaining popularity for its paradigm shift towards its city-wide/outdoor ubiquity availability (Arsalan, Burhan, Naseer, & Rehman, 2022).
There are several reasons which show that WiFi is an efficient solution for mobile data offloading. Firstly, we can see that WiFi is available in many indoor areas like residential buildings, train stations, shopping malls, airports and different private and public locations. Secondly, it seems feasible the deploy WiFi in outdoor areas by the operators. Also, because of advancements in technology, most of the end-user devices like laptops, smartphones and tablets contain WiFi interfaces (Ahmad, Manzoor, Naseer, Ghaffar, & Hussein, 2021; Benkirane et al., 2023). Last but not least, energy efficiency, less cost and sharing the load from mobile networks are some of the key benefits of WiFi offloading. There are different ways to categorize the WiFi offloading. Delayed and non-delayed WiFi offloading are explained in (Rebecchi et al., 2015) based on the data traffic nature and the delay requirements that can be tolerated by the users in the delivery of data. Whenever a device has some delay constraints on data delivery and has priority to choose the WiFi interface rather than the cellular interface, it offloads its data by using ***non-delayed or on-the-spo****t* offloading. In this strategy, until a user remain in wireless coverage of WiFi area then data is offloaded to the WiFi network and when the user crosses this coverage then data flow continues on cellular links to encounter the delay requirements (Abrar et al., 2021). Conversely, in ***delayed*** data offloading, when the user can tolerate some delays in data delivery, then data transmission remains stopped while the user's device comes out of the signal range of the WiFi network and resumes again when it re-enters in signal coverage area of WiFi. The significance of this shallowness can be evident when there are long deadline delay requirements and delayed offloading is used to reduce the burden on the cellular links (K. Lee, J. Lee, Y. Yi, I. Rhee, & S. Chong, 2013). The experimental results of (Cheng, Lu, Zhang, Shen, & Mark, 2014) showed that 65% of the cellular traffic can be offloaded by using non-delayed offloading and it can be improved up to 82.1% if we use the delayed offloading strategy. For both the operator and subscriber, delayed offloading is more desirable from an economical point of view. Results in (Cheng et al., 2014) indicate that it raises the revenue of the operator from 21% to 152% and from a user point of view it reduces cost and energy from 73% to 319% in comparison to different scenarios of non-offloading (Velusamy et al., 2021).

For operators, depending upon the integration of cellular and WiFi Networks there are three main categories unmanaged data offloading, managed data offloading and integrated data offloading (K. Lee et al., 2013).

a. Unmanaged data offloading or Network bypass:

in this case whenever there is a WiFi coverage area the user secession is transferred from the cellular network to the WiFi network and it bypasses the core cellular network for data-oriented services. Whereas voice-oriented services remain to be continued on the cellular core network. It is a simple and attractive approach because we don't need to apply any modification to network infrastructure, but there exist some drawbacks to this strategy. First, when a user is in a WiFi coverage area the operator loses control over the user. Second, the subscribed content (Corporate VPN, Blackberry, ringtones etc.), can't be delivered by the network operator and it leads to revenue loss for the network operator. Regardless of its drawbacks, it can be adopted as a candidate offloading approach because of its easy deployment. This technique is also useful from the user's point of view because of user control over data delivery. It is very similar to switching on the user's device WiFi interface whenever it is in the WiFi coverage area. Operators can implement this offloading scheme very simply by installing an application program on the user's device that automatically switches on the Wi-Fi interface whenever it detects a WiFi coverage area (Naseer & Mahmood, 2015)

b. Managed data offloading:

To get some control over the subscriber, different operator uses the managed data offloading approach. In this approach, a secession-aware gateway is placed intelligently by the operator to monitor the subscriber's secession under the coverage of WiFi on its way to the internet. Full integration of WiFi providers and the cellular network is not required in this approach and the operator can get control over the end-user, again it can't manage the delivery of subscribed content (Sandhu, Haider, Naseer, & Ateeb, 2011).

c. Integrated data offloading:

To get full control over end-users and to transmit subscribed contents under the coverage of the WiFi network to the subscribers operator uses an integrated data offloading approach. In this technique, data flow can be managed by a bridge between these two networks and it can be accomplished by integrating WiFi and cellular networks. There are two approaches to integrating WiFi and cellular networks tight coupling and loose coupling. In ***loose coupling***, no cooperation is required between these networks and both are independent in this integration (Ali, Khan, & Naseer, 2022). In this strategy, both networks are connected indirectly by some other IP network like the Internet. Service is provided by the concept of roaming between these two networks. Whereas in ***tightly coupled*** architecture both networks share the common core and the WiFi network is also managed by cellular network operators. Most of the network functions like billing, resource management and vertical handover are managed and controlled centrally. For cellular network operators, the 3GPP I-WLAN standard describes the offloading scenario and basic principles of integrating both networks ("3GPP system to Wireless Local Area Network (WLAN) interworking; System description,"). It defines a solution how for transferring data from the cellular core network and end device with the help of a Wi-Fi access network (Naseer, Ghafoor, bin Khalid Alvi, & ul Islam, 2022). The main idea is, to establish a tunnel between a dedicated I-WLAN server and an end device in the core network, to get access to the public internet or the operator's subscribed contents.

d. White-Fi offloading:

The IEEE family define a standard IEEE 802.11 af, with the name of White-Fi. It is a proposal of cognitive radio for using traditional WiFi in the white space spectrum band of TV by using cognitive radio techniques. The white space band of a TV refers to a band that will be available by a switch over from analog TV to digital TV on a geographical basis. There are many advantages of White-Fi, like wide area coverage because of better-broadcast characteristics of the TV signal spectrum band and having much higher bandwidths (location dependent, e.g. on average 50-150 MHz in the UK(Nekovee, 2009). It is expected that in future, White-Fi hotspots should be installed for mobile data offloading from cellular networks to get good throughput. Nevertheless, channel aggregation techniques will be required to get good data rates that will be comparable to the data rates of Wi-Fi bands (Arshad et al., 2023).

2.1.2 Vehicular Wi-Fi Data Offloading:

Moving Vehicles on the road and roadside APs of WiFi Networks can be used as a practical solution for data cellular data offloading, called vehicular Wi-Fi offloading. The research in this direction has an objective to enhance the cellular data offloading performance, particularly for delay-tolerant and non-interactive applications.

For non-vehicular users different offloading strategies mainly emphasise offloading performance and availability of the next approaching WiFi AP because a user wants to have a stable communication link with one WiFi AP. This thing does not apply to vehicular WiFi communication. Since vehicles have fast speed and in a short period they may meet more APs having different quality of communication links and may have more opportunities to transmit data. Therefore, offloading strategy in these scenarios should consider the prediction of forthcoming WiFi APs to get the advantages of more data transfer opportunities. Delay requirements of an application would have significant impacts on mobile data offloading schemes. Different non-interactive or non-real-time applications, such as regular sensing data transmission to control unit, bulk data transmission from smart meters to smart girds and email attachments are usually throughput-sensitive and can compromise on delays of certain time limits (Arshad et al., 2023).

Literature shows the different proposals for vehicular WiFi offloading strategies (Balasubramanian, 2010; Hou, Deshpande, & Das, 2011). Wiffer is proposed as an offloading strategy in (Balasubramanian, 2010), which determines when to defer data transmission of an application for WiFi connectivity rather than using communication over the cellular network. Wiffer calculates the delay requirements of each application and predicts the calculations of the throughput potential of WiFi, based on the history of the vehicle's route. Based on these calculations it performs the data offloading. To study the performance and availability of 3G and WiFi networks an experiment is conducted, by placing WiFi APs at more than half of locations in the city, results showed that 20% of cellular traffic can be reduced by data offloading through drive-thru WiFi, also due to mobility of vehicles the temporal availability of WiFi is low (12% of the time). Wiffer handles delayed offloading and for delay-sensitive data applications, it performs fast switching to cellular networks. VU's preferences or binary names or port number information are used to determine the delay tolerance of an application (Satti et al.).

The effective throughput of WiFi can be estimated or predicted by calculating the number of contacted APs in the history. This prediction is based on the duration of inter-contact time of each encounter and it can be the same in future as in the historical average. Based on these predictions WiFi offloading is performed if $W>S.c$, where S is the Data size needed to be transferred within the given delay constraints, c is the conservative quotient that is used to manage the trade-off between application completion time and offloading effectiveness and W is effective throughput of WiFi based on prediction. For real-time or delay-sensitive applications, Wiffer uses fast switching from WiFi to the cellular network when WiFi fails to transmit data packets within a predefined threshold time (Naseer, Saleem, et al., 2023).

Motivated by the experimental results of (Balasubramanian, 2010) which showed that mobility and connectivity with AP of the moving vehicles can be predicted, (Deshpande, Kashyap, Sung, & Das, 2009) proposed a data prefetching strategy. In this approach, data is pre-fetched and cached in APs along the predicted route of the vehicle, transmitting these data contents to the vehicles when they are in their wireless range. This exploits the vehicular WiFi offloading because vehicle-to-AP uses point-to-point communication having higher bandwidth than backhaul bandwidth. Moreover, vehicle-to-AP communication can use some special type of transport layer protocols like CTP (Eriksson, Balakrishnan, & Madden, 2008) having less porn to wireless losses than TCP. Data pre-fetching is based on the mobility prediction model of the vehicle, to manage the mobility prediction errors, data is redundantly pre-fetched along the predicted APs on the route. Nevertheless, in recent years backhaul capacity of WiFi has been boosted greatly, which is why the benefit of data prefetching might be reduced (Naseer, Ghafoor, bin Khalid Alvi, Zafar, & Murtaza, 2023).

To enhance the throughput of Vehicular WiFi offloading strategy is also proposed at the transport layer (Deshpande et al., 2009). oSCTP is presented for data offloading of cellular networks via WiFi and enhances the user's benefit. oSTCP uses both WiFi and cellular interfaces at the same time if necessary, and after each time interval, it schedules data packets for each interface. Experimental results showed that oSCTP offload data traffic from 63% to 81% and it validate the effectiveness of oSCTP as a data offloading technique (Khan et al., 2023).

2.1.3 WiFi Deployment

Data offloading also depends upon the density and deployment strategy of WiFi APs. It has been shown that by deploying 10 APs in the area per square kilometre, the average throughput per user can be increased up to 300% and this gain is proportional to the AP Density (Hu, Coletti, Huan, Mogensen, & Elling, 2012). In other words, we can say that if we increase the number of APs in a geographical area then we can get better performance of cellular data offloading. On the other hand, dense deployment of APs may increase the operational cost and expenditures. Hence there is a trade-off between offloading performance and AP deployment cost and it should be examined properly. WiFi deployment strategy plays an important role in getting better throughput. Many factors should be considered to make a good strategy for deploying APs, like vehicle mobility, communication environment, population density mobile data usage etc (Naseer, 2021).

In (Kyunghan Lee, Joohyun Lee, Yung Yi, Injong Rhee, & Song Chong, 2013), the performance of mobile data offloading is investigated against WiFi deployment. This study identifies the APs having the least sessions and user connection times and gradually eliminates those APs to get the performance with different densities of APs. It is identified that even 80% of the WiFi APs are eliminated, whereas the offloading performance is dropped only 10% to 20%, which shows that only a few well-deployed APs can contribute to better performance of data offloading with less cost. WiFi deployment for location popularity is presented in (Dimatteo, Hui, Han, & Li, 2011) and (Ristanovic, Le Boudec, Chaintreau, & Erramilli, 2011). Location popularity means locations visited by a high frequency of users. Experiments are conducted in an area of 313.83 km^2 with a deployment of several hundred APs at prime locations and results show that half of the cellular data can be offloaded efficiently on WiFi networks. It is also identified in (Bulut & Szymanski, 2013) that most visited places are not definite sources of high data traffic generation. Therefore, by identifying the frequency of data traffic requests, another WiFi APs deployment approach is proposed and evaluated in.

Three strategies of WiFi deployment, namely, uniform random, traffic-centric and outage-centric are proposed and evaluated in (Hu et al., 2012). In outage-centric and traffic-centric APs are placed by considering the outage and locations having the highest data traffic requests respectively, whereas Uniform Random APs are deployed uniformly and randomly and deployment metrics are not considered. Results showed that by deploying 10 APs per km^2, in traffic-centric average throughput gain was 300%, and the outage was reduced by 14% in an indoor environment by using an outage-centric approach.

2.2 Data Offloading by Licenced Frequency Band (Small Cell)

For indoor (e.g., in the office or home) cellular communication, femtocells are used as a small base station. These BSs are connected to the provider's core network via some broadband network (e.g., DSL, digital subscriber line) and it helps to service provider to provide its services in indoor coverage areas, like the areas where service is unavailable or limited. Femtocells are more attractive solutions for operators because they offer improvements in capacity and coverage to macro cells, especially indoors. This concept applies to all cellular standards e.g. GSM, World-Wide Interoperability for Microwave Access (WiMAX), wideband code-division multiple access (WCDMA) and LTE. Femtocell introduced effective ways for reducing the data traffic load over the microcell. They improve the experience of mobile users on macro cell BS by freeing the capacity and on the other hand users on the femtocell get improved performance due to having better radio resources.

Mobile data offloading by using femtocells is also efficient because of different reasons ("Femtocells — Natural Solution for Offload," 2010). First, the data usage occurs mainly in an indoor environment (office or home). In (Aijaz, Aghvami, & Amani, 2013; Putti, june 2010), it is explained that data usage occurrence is 26% in the office and it is 55% at home. It shows that the operator can offload heavy data traffic via femtocells. Second, femtocell services are deployed and managed by the operator and it provides a seamless service experience to end-users. Third, femtocell installation is easy as compared to macro cell BS deployments which involve huge costs of backhaul, infrastructure site acquisition etc.

In a femtocell network, data traffic flows from the user equipment to the femtocell's small BS by using an air interface, which is connected to some broadband connection, and then from this broadband internet to the provider's core network or/and other destinations of internet. The user's equipment (UE) is automatically connected to small BS whenever a user comes in the range of femtocell frees the macro cell BS resources and traffic flows through the user's broadband connection. The use of femtocell not only offloads the traffic from NodeB(in 3G) or eNodeB(in 4G, LTE) but also frees resources of the radio network controller(RNC), which leads towards the further load reduction of the macro cell.

In (23.823), a new standard, selected IP traffic offload (SIPTO) is explained, in which the operator offloads a certain type of data traffic at a node that is close to the location of end-user equipment.
Two types of approaches are explained in this standard, deep packet inspection (DPI) based and access point name (APN) based. In the implementation of SIPTO operator can offload the data traffic from the core network by the direct traffic flow from femtocell to the internet.

2.2.1 Small-Cell-Based Offloading

Small cells operate in the licensed band of the energy spectrum and they are access points having low power as compared to macro cells. These cells provide better cellular coverage and improve capacity and application services for home and enterprise users at metropolitan and rural public spaces. There are three types of cells based on signal transmission power and coverage area in terms of radius as shown in Table 1.

TABLE I. COMPARISON BETWEEN CELL TYPES

Characteristic	Femto	Pico	Micro	Macro
Power	20mW	200mW - 2W	2W	greater than 2W
Coverage	Hot Spot	Hot Spot	Wide Area	Wide Area
Configuration	Automatic	Automatic or Manual	Automatic or Manual	Manual
Location	Indoor	Indoor or out door	Out Door	Outdoor
Density	Large Number	Large Number	Small Number	Small Number
Service Location	Designed for data	Designed for Data	Designed for Voice	Designed for voice

Small cell-based data traffic offloading has two approaches: (1) User-oriented traffic offloading, (2) Network oriented offloading.

a. User-oriented traffic offloading:

It investigates the performance enhancement of user equipment through femtocell traffic offloading. MUs can get benefits in terms of radio resource utilization, data cost and energy consumption. Due to non-ideal backhaul as well as intermittent and limited small cell coverage, data offloading might cause some additional delay. Hence, it is critical to comprehend under which conditions there will be the benefit of data traffic offloading and how it can be adjusted for a trade-off between the benefits from data traffic offloading and consequential disadvantages.

In (Cheung & Huang, 2015), Cheung et al. find the data transmission delay for offloading data in a cell and optimize the data offloading problem concerning MU's data cost and resultant delay performance in file transfer. In (Lee, Yi, Chong, & Jin, 2013; Zhuo, Gao, Cao, & Hua, 2014) the authors suggested different proposals, to give incentives to users and exploit delay-tolerance for data traffic offloading in a small cell to reduce the burden on the macrocell. In (Im, Joe-Wong, Ha, Sen, & Chiang, 2016), the author proposed a cost-aware data offloading scheme and considered the budget of MU's data usage, formulating and optimising the offloading problem concerning throughput and delay trade-off.

b. Network-oriented Traffic Offloading:

This strategy emphasises the study of network performance improvement by traffic offloading using a small cell. Strong coupling exists among cellular users when data offloading occurs in small cells because of intercell interference and limited radio resources. For example, when data offloading occurs on the same band in nearby cells then severe intercell interference may occur. Moreover, severe collision and interference occur when several mobile users offload huge amounts of data in the same cell. That's why, to measure offloading performance gain, we must consider the overall network performance enhancement by data traffic offloading using small cells.

In(Ho, Yuan, & Sun, 2014), authors measured the interference, during traffic offloading among different cells. They evaluated the overall network performance by formulating a utility maximization problem aiming to distribute traffic offloading in different cells. In another research (Chen, Wu, Cai, Zhang, & Chen, 2015), Chen et al. consider the energy efficiency of the overall network by considering the interference in small cells and define an optimal on-off controlled strategy for data traffic offloading. In (Kang, Chia, Sun, & Chong, 2014), the authors measured the co-channel interference in the same cell among different mobile users by considering and maximizing the overall network performance and defined an optimal solution to the user-association problem. A social welfare optimization problem is defined and formulated by Iosifidis et al.(Iosifidis, Gao, Huang, & Tassiulas, 2015) that distribute the demands of data traffic offloading in different cells by considering the limited resources of the overall network.

Media Optimization and other solutions

Media optimization is indirectly related to the concept of mobile data offloading, it uses different techniques to reduce network congestion by mitigating data traffic load on the network, and subsequently, it improves user's QoE and network resource utilization among different subscribers. To implement such type of solution, an optimization server is usually placed between the cellular core network and the internet. In (Aijaz et al., 2013), the most commonly used solutions are formulated and explained. These media optimization solutions are described here as follows

3.1 Video Caching

Sometimes popular video content can go viral on the internet in a short period. It may increase the traffic load on cellular network infrastructure. One of the best solutions to deal with such type of video content, it should be cached closer to the end-users, rather than to get from the main server at each repeating request. To get the more effective solution, a media optimization server should be installed in the network and it should pre-fetch the most popular contents of videos and store them in the cache according to the type of different devices, and consequently it forwards the optimized video contents from the cache whenever user send the request.

3.2: Dynamic Bandwidth Shaping

To enhance the user experience, the media optimization server can adjust the data rate of encoded video at run time according to the available bandwidth of the user. It improves the user's QoE by limiting the screen freeze that usually happens when the user's available bandwidth is less than the incoming bit rate of the video.

3.3: Web Optimization

Web optimization is similar to media optimization solutions. It provides faster browsing and prompt access to the requested contents by expediting information exchange rates over cellular networks by using different strategies, for example, investigating the data traffic and storing the optimized version of the most demanded sites in the cache for faster access. It also improves the load time of web pages by removing comments and redundant white spaces from HTML pages, and by pipelining HTTP requests.

3.4: Cognitive Radio

The available cellular spectrum is already overcrowded for mobile operators, whereas some other portions of the energy spectrum band are in less use or relatively unused. These available frequencies, bandwidth and less use may lead to an opportunistic use of available and unoccupied spectrum (Akyildiz, Lee, Vuran, & Mohanty, 2006). The cognitive radio technique finds the unused frequencies at run time and dynamically shares them with other users without making any significant interference. Overall network performance and capacity can be enhanced by sharing these unused bands and frequencies (Berg & Katsigiannis, 2012). Cognitive radio can also be used in cellular networks to offload the cellular traffic (Grønsund, Grøndalen, & Lähteenoja, 2013), in combination with a heterogeneous network paradigm (ElSawy, Hossain, & Kim, 2013). Cognitive radio technologies can thus be capable of enhancing energy spectrum efficiency and surge network capacity efficiently.

3.5: Multicasting/Broadcasting

When multiple users in a proximate area ask for the same data contents, in such type of use cases multicasting could be an effective solution for cellular data offloading. Multicasting can use a single radio channel, to share the same data contents among several users within the same cell of mobile network. Multicasting is an ingenious technique to provide data content to multiple proximate users by exploiting the redundancy of requests, allowing in principle better resource utilization and saving. Multicasting has some inherent and unresolved issues that limit its exploitation. Each user at a different distance from the base station experiences different channel conditions. This variation in link conditions seriously decreases the efficiency of multicasting, since the cellular base station must have to use a uniform modulation to confirm success to each user. Mobile users who are near BS can decode the signal efficiently and get higher data rates, whereas the users near the boundary of the cell may get lower data rates because of weak signal quality. Hence, the user with the worst channel conditions dictates the performance, lowering the throughput of multicasting. That is why data offloading can also be efficient in the case of multicasting, as explained in (Rebecchi, Dias de Amorim, & Conan, 2014).

Data offloading using vehicular network

This work introduces a comprehensive framework for efficient data collection in smart cities, leveraging the dynamic mobility of vehicular networks to overcome challenges posed by traditional fixed infrastructure as shown in the figures. With the rapid growth of smart city applications and IoT devices, effective and scalable data collection methods have become critical for urban management. The proposed framework employs vehicles as mobile data carriers, dynamically connecting to IoT sensors and infrastructure to gather and transmit real-time data.

The framework is designed to address key challenges, including energy efficiency, secure data transmission, and scalability. It integrates vehicular mobility models, adaptive routing protocols, and data aggregation techniques to ensure seamless and reliable data collection in dense urban environments. The research also incorporates advanced machine learning algorithms for predictive analytics and decision-making, enabling proactive responses to urban issues such as traffic congestion, pollution, and resource management.

Comprehensive simulations and real-world testbed evaluations were conducted to assess the framework's performance. Results indicate a substantial improvement in data transmission reliability, reduced latency, and enhanced energy efficiency compared to conventional approaches. The findings highlight the potential of vehicular networks to revolutionize urban data collection by reducing dependency on costly fixed infrastructure while promoting sustainability and scalability.

This research contributes significantly to the fields of smart cities, vehicular networks, and IoT, providing a robust solution to meet the demands of modern urban environments. The proposed framework lays a strong foundation for future developments in smart city infrastructure, enabling intelligent decision-making and efficient resource utilization to support economic growth and improve the quality of urban life (Naseer, 2021).

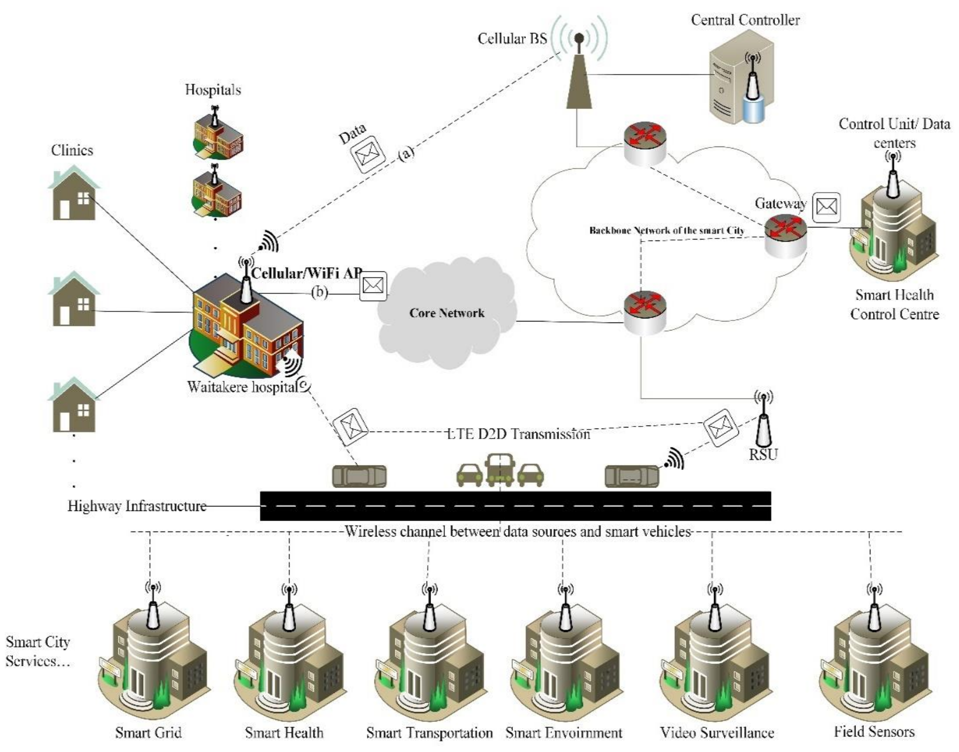

Figure 3: Energy efficient data dissemination framework using vehicular network(Naseer, 2021)

Comparison with different existing techniques

Table comparison indicates our proposed framework, the vehicle-assisted energy-efficient data dissemination framework, compared with other existing works. Apart from Amazon, most of the existing works utilise radio communications for transferring data to or from vehicles. Although Unmanned Aerial Vehicles (UAVs) is the comprehensive body of work for data transfer, this method is not sufficient for covering all areas due to inheriting battery restrictions. UAVs are not reasonably cost effective and they are inadequate in numbers. From the security point of view, questions have been raised as to whether it is secure to use UAVs for data mules. Advanced scheduling is needed for Amazon Snowball and Snowmobile while transferring data (of this method) is not free for the user. If data transferring via snowmobile is on a large scale, tens of days are taken to schedule this transfer for each appointment (Coutinho, Queirós, Henriques, Norton, & Alves, 2018). Researchers cannot benchmark their routes or algorithms of vehicle selection through other related contributions because these sources are not made freely available to the general public.

To transfer data from source to destination of a single hop or multiples', our framework has been proposed which is based on the vehicles and uses the intermediate nodes RSUs. As smart vehicles and smart cities have become popular, vehicles can take the role of transferring data to spend less energy on network communication. If data is transferred through a communication network, other applications are affected in addition to blocking the entire network. The average rates of uploading and downloading data in traditional data-transferring networks are also different from continent to continent. For instance, transferring 20TB of data would take around 38 months in Africa, whereas this amount of data is transferred by around 4 months in Australia. It is noted that only the time of uploading is considered in this case scenario and both the time of transferring and downloading have been neglected (Renquist, Jeng, Mason, & Contributors, 1992).

Discovering the optimal route between the source and the destination is the responsibility of the controller in the proposed framework. The controller also decides about the suitability of transmitting data via traditional or vehicular networks. To decide, the time of transfer and the availability of volunteer vehicles close to the source for starting and close to the source or destination for continuing are considered. We have an interest in adding more complex algorithms to calculate the path of transferring from source to destination in the future.

Energy – to transfer data, the Internet has been in use across the world traditionally. The energy which is consumed for communication through the Internet can be grouped as the end-user cost. While this energy is around 38% of the total energy consumption, the remaining 62% of energy supplies the network nodes of repeaters, routers, servers, switches and centres (Costenaro & Duer, 2012).

Costenaro and Duer had approximate calculations on the consumed energy by the Internet in kWh per GB as 5.12 kWh/GB according to the parameter values used for Internet data transfer and concerning core network devices. Therefore, to transfer 20TB of data, a total of 102.4 MWh of energy is estimated for consumption by the Internet data. From another standpoint, the average power consumption of a server equal to 145 watts per hour has been considered according to the research work of Pries et al. (Pries, Jarschel, Schlosser, Klopf, & Tran-Gia, 2012) to calculate the consumed energy using vehicles for transferring data. Whereas in our proposed case it consumed 60.66 MJ energy to transfer 20 TB of data by using vehicles. To determine the total cost in both scenarios, the average electricity cost as standardized by the U.S. Energy Information Administration equal to i.e. $0.112 per Kilowatt hour (kWh) has been taken into account (Carroll & Heiser, 2010). As a result, the cost of energy of the system for 20 TB is estimated as $11469 approximately according to the energy consumption for transferring data via the Internet. Meanwhile, the cost for the proposed vehicular approach is approximately $1900 approx.

Based on the above discussion, (Naseer, 2021) indicates the energy consumption by a variation on the amount of transferred data, while utilising the Internet or the proposed vehicular approach. Therefore, the performance of our vehicular-based data dissemination approach is of superior quality and excellence in comparison with the Internet data transfer in the context of both the energy and the delay.

One of the important implications of our proposed work is the business of the sharing economy. The business of the sharing economy is a mode of purchasing services and goods that is different from the traditional model of business (Puschmann & Alt, 2016). In the traditional model, we hire employees to produce the products and then we sell them to customers. On the other hand, in a shared economy, people are supposed to rent out their things like private time, cars, and homes to other people in a peer-to-peer manner, e.g. Uber and Airbnb. In our proposed work, people have their cars the can take part in this business of shared economy based on some incentives for this data and code dissemination in SCs.

Moreover, we consider the bi-directional mode of communication in our proposed framework. In most of the previous work, the data communication mode is unidirectional i.e. from source to destination. In our work, we consider big data migration, data transmission from SSs to service providers and code transmission from service providers to SSs.

Previous Work	Disk capacity	Transfer Frequency	Data Trans. Mode	Route requirement	Platform	Comm. between devices	Message Direction	Reliability of Trans. tasks	Energy Efficiency	Business of Sharing Economy
Cheng et al.	Undefined	Undefined	Unmanned Aerial Vehicles	Actual flight paths	-	Radio communication	Unidirectional $S \rightarrow D$	×	×	×
Palma et al.	Undefined	Scheduled own resources	Unmanned Aerial Vehicles	Fixed route	Emulated Environment	Radio communication	Unidirectional $S \rightarrow D$	×	×	×
Usbeck et al.	Undefined	Scheduled own resources	Unmanned Aerial Vehicles	Unspecified networks	Android Platform	Radio communication	Unidirectional $S \rightarrow D$	×	×	×
Hunjet et al.	Undefined	Scheduled own resources	Unmanned Aerial Vehicles	Tactical network	MASON framework	Radio communication	Unidirectional $S \rightarrow D$	×	×	×
Amazon Snowmobile	100PB	One time and Scheduled on demand	Large container truck	Limited specialised regions	Amazon Big Vehicle	Wired	Unidirectional $S \rightarrow D$	×	×	×
Amazon Snowball	<100TB	One time and Scheduled on demand	Large container truck	Limited specialised regions	Amazon Big Vehicle	Wired	Unidirectional $S \rightarrow D$	×	×	×
Rashmi et al.	2TB	Scheduled own resources	Public buses	Based on User Profiles	ONE Simulator	Wifi-direct	Unidirectional $S \rightarrow D$	×	✓	×
Coutinho et al.	Undefined	Scheduled own resources	Boats	Unspecified network	ONE and NS2	Radio communication	Unidirectional $S \rightarrow D$	×	×	×
Proposed System	Independent of disk size	Scheduled by CC on each demand	Any vehicle can participate	Independent of vehicle trajectory	Modeling / Data driven approach	Virtus Chipsat/ WiFi-direct	Bidirectional $S \leftrightarrow D$	✓	✓	✓

Conclusion

Mobile data offloading presents a promising solution for alleviating cellular network congestion at a minimal cost, enhancing user experience by providing high-quality network access while addressing the persistent issue of RAN overloading. This survey underscores the advantages of utilizing alternative mobile access networks for offloading data. It explores the concept of mobile data offloading, highlighting its significant benefits, associated technological challenges, and ongoing research trends. Specifically, it offers a comprehensive classification of existing offloading strategies, focusing on their delivery guarantee requirements. Finally, we provide a concise overview of our proposed approach and compare it with existing techniques. The tabular comparison highlights the effectiveness of our system across various scenarios, demonstrating its superior performance in addressing diverse challenges.

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