A Survey on the Performance of Commercial Mobile Access Networks

SnT Technical Report

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***Abstract*—In this paper we present a performance study on different commercial access networks. The survey is divided in two parts. First, we investigate the nominal performance of the networks by probing performance metrics at several locations in a predefined area. In a second part we test how the performance is affected by taking measurements while on the move. The outcome of our study shows that there are significant differences between the tested access technologies. Further, we found that in most cases, the mobility does not considerably lower performance of the network, whereas other factors such as the number and location of the base stations play a important role.**

***Index Terms*—Performance Study, Commercial Mobile Networks, EDGE, HSPD, WiMAX, LTE**

I. Introduction

The mobile Internet is growing rapidly. It is expected that by 2015, mobile Internet users will surpass the number of wireline users [1]. Already today, most consumers having smartphones or tablet PCs have a mobile data plans providing broadband Internet services while on the move. In the future this trend will be amplified with the emergence of new mobile services enabled by vehicular communications (e.g. community contributed traffic information, smart navigation services) [2]. It is clear that part of the data traffic required for those applications will be routed over mobile networks, which provide a direct link to the Internet.

In this work we are going to benchmark several commercial access networks in the area of West Los Angeles and discuss their limitations and strengths. In a first phase, we investigate the nominal performance of the networks by probing metrics such as, download/upload bandwidth and latency at different randomly chosen locations on the Westside of Los Angeles. To compare how the different technologies react to mobility, we then performed a performance study, which consists of downloading respectively uploading a data stream from/to a remote web server.

The outcome of our study shows that there is a large performance gap between the different tested technologies. The more recent 3G/4G technologies provide moderate to excellent service, which would be sufficient to support a wide range of future mobile applications. However with the increasing number of mobile users, the infrastructure needs to be continuously extended to meet the growing traffic and Quality of Service (QoS) demands. Further, we identified that urban mobility does not play a major role in the performance of the network. Factors such as the number and location of the base stations play an important role.

The rest of this paper is organized as follows. In Section II we provide a brief overview of the existing mobile network technologies. In Section III we discuss the experimental setup. The results are presented in Section IV and a conclusion is drawn in Section V.

II. Technologies Overview

In this Section we will provide a brief overview of the currently available access technologies and how they are marketed. It is important to point out that the technologies behind the marketing terms (i.e. 2G/3G/4G) heavily differ from one mobile operator to another. In the following subsections we will review the most commonly used technologies that provide mobile Internet services and describe their characteristics. For more detailed information on the various existing technologies, the reader is referred to the technical literature.

A. General Packet Radio Service

General Packet Radio Service or short *GPRS* is a packet oriented mobile data service that operates on the GSM band. It is often referred to as a 2G technology and provides moderate data rates between 56 and 114Kbit/s. The multiple access schemes used are based on frequency division duplex *(FDD)* and time division multiple access *(TDMA)*. The definition of a multi slot class defines the throughput in uplink and downlink direction. For instance, it is possible to allocate multiple time-slots to an Uplink or Downlink connection based on the available resources.

B. Enhanced Data Rates for GSM Evolution

This technology, usually referred to as *EDGE*, is an extension of GPRS and is therefore backward compatible with the GSM band. Instead of using four coding schemes, EDGE uses nine different modulation and coding schemes allowing peak bitrates of up to 1Mbit/s. On everyday usage typical bitrates of 400Kbit/s can be expected. This technology is often referred to as 2.5G as existing 2G GSM networks can easily be extended to provide EDGE data service.

C. Universal Mobile Telecommunications System

The Universal Mobile Telecommunications System or *UMTS*, is a third generation (3G) mobile cellular technology that operates on a different frequency band than GSM. It uses Wideband Code Division Multiple Access *(WCDMA)* that offers better spectral efficiency and bandwidth to the mobile users. In its first release, UMTS networks supported bitrates of up to 384Kbit/s. Nowadays, most commercial UMTS networks have been upgraded to support the far more efficient High Speed Packet Access *(HSPA)* protocols.

D. High Speed Packet Access

An evolution of the classical 3G/UMTS network is commonly know as the High Speed Packet Access (HSPA) which is composed of a downlink *(HSDPA)* and an uplink *(HSUPA)* protocol that improve and extend the spectral efficiency of the existing WCDMA protocols. HSPA supports increased peak bitrates of up to 14Mbit/s in download and 5.76Mbit/s in upload depending on the network load. A further improvement, also known as *HSPA+* or *Evolved HSPA*, was released in late 2008 and is currently getting widely implemented on commercial mobile networks. The novelty with HSPA+ is that it used a multiple-antenna technique known as *MIMO* and higher order modulate. In practice, transfer rates of up to 42Mbit/s can be expected. Depending on the operator, this technology is usually advertised as 3.5G or even 4G as it provides speeds that are comparable to newer technologies such as LTE.

E. WiMAX

Worldwide Interoperability for Microwave Access or *WiMAX* is a wireless communications technology that operates on a dedicated licensed spectrum [1]. In order to support high bitrates, WiMAX uses a Orthogonal Frequency Division Multiplexing *OFDM* method that encodes digital data on multiple carrier frequencies. It has originally been developed as a last mile wireless broadband technology to compete with conventional wired Internet connections such as DSL and CABLE. In its first release, the standard has been specified to provide bitrates between 30 and 40Mbit/s. In the 2011 update, the specifications claim that bitrates up to 1GBit/s can be reached. Commercial WiMAX networks have mainly been deployed in the US and Asia and are usually advertised as high-speed 4G networks.

F. Long Term Evolution

Long Term Evolution or *4G LTE*, is the latest standard for high-speed mobile communications. Peak download data rates of up to 300Mbit/s and upload rates up to 75Mbit/s can be reached. Although it is mainly advertised as a 4G technology, the standard has been developed by the third generation partnership project *(3GPP)* to increase the capacity and speed of the existing UMTS/HSPA networks using a new modulation technique. LTE uses a similar modulation scheme (OFDM) for the downlink communications as WiMAX. For the uplink communication it uses *SC-FDMA* which is more energy efficient. Low latency and improved support for mobility are only a few new features that make LTE more efficient than competing technologies such as WiMAX and HSPA+. The adoption of LTE as a commercially mature technology has started in 2009 with the launch of the first network in Oslo and Stockholm. Today most major network operators in the US, Europe and Asia are in the process of deploying commercial LTE networks.

III. Experimental Setup

All of the conducted experiments have been performed on and around the UCLA campus in the Los Angeles metropolitan area [2]. In this densely populated area, all major mobile network operators claim to have a full coverage of their advertised services. Table I, provides an non-exhaustive list of the local operators and their respective *advertised* services. As we can see from this table, the technology behind the term 4G is not always the same. As described in Section II, there are significant differences in terms of bandwidth, latency and mobility depending on the communication standard used.

For our survey, we tested all of the operators/services listed in Table I, expect Verzion 4G due to contractual constraints. Further, all operators expect Clear provide the full range of mobile services (Voice calls, Text messages and Data) whereas Clear only provides broadband mobile data. Consequently, for most of our tests, we used mobile phones as tethering devices connected to a Laptop to send and receive the data traffic. To test the Clear network, we used the dedicated USB modem for the same purpose.

The survey has been divided in two main parts. The first being the static tests where we tested the network performance at different fixed locations. For this we used the well know network diagnostic tool *SpeedTest* [3], that provides information on the downlink and uplink characteristics and on the latency. In order to provide more meaningful results, the probes have been repeated for every tested service at ten different locations on the Westside of Los Angeles and averaged out.

In the second part we conducted several mobile experiments in which we continuously download respectively upload a TCP flow from/to a remote web server while driving. Figure 4(a), shows the mobility scenario used to that purpose. The idea was to test the different wireless network technologies in a realistic urban environment (e.g. stop and go mobility and building blocks). However, as there are too many unpredictable events (e.g. traffic variations/jams, accidents), repeating experimental runs are usually difficult to perform in a real-life scenario. That's why we decided to perform our runs on the UCLA campus, which provides the same characteristics and allows us to better control the experimental runs.

In our scenario, the vehicle circles around the *Engineering IV* building which has the equivalent size of a small city block. The total distance of one lap is approximately 400m. In one experimental run, we circle the block twice which takes on average 120s resulting in a average velocity of around

[1]The spectrum profiles might change depending on the region/country

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6.6m/s or 24km/h. Per lap, there are 4 different stop signs (S1 to S4) where S1 is the start and end position. Please note that in order to avoid additional signal attenuation, the communication devices (i.e. smartphones & USB modem) have been fixed outside the vehicle.

TABLE I
OPERATORS AND ADVERTISED SERVICE VS. TECHNOLOGY.

Operator & Service	Network Technology
T-Mobile 2G	EDGE
T-Mobile 3G	HSPA
Sprint 3G	HSPA
AT&T 4G	HSPA+ and LTE
Sprint 4G	WiMAX
Clear 4G	WiMAX
Verizon 4G	LTE

IV. RESULTS

In following two subsections we will present and discuss the results obtained during our different test runs. In the first subsection we will start by a static study in order to identify the nominal performance of the networks. In the second subsection, we will go one step further by testing how the performance is affected due to mobility. The main motivation here is to see if those technologies are suitable for vehicular communications and identify the limitations.

A. Static Tests

For the static survey, we tested five network operators providing four different communication technologies. The complete list of the tested operators and the corresponding technology can be found in Table I. As we do not know the location of different base stations, we decided to probe the network at ten random locations on the Westside of Los Angeles in which the operators claim full service. We used the web-based diagnostic tool *SpeedTest* to obtain the following metrics: download speed, upload speed and network latency. For every metric we present the minimum, maximum and average value.

Figure 1 shows the results for the download tests. As expected, the newer the technology, the higher the throughput. However none of the tested technologies provides the performance as advertised in the specifications. There are several reasons for that. The first and the most obvious is that the shared medium (frequency band) is accessed by multiple users at the same time, which, based on the modulation used, lowers the overall throughput per user. Environmental interferences, shadowing and distance to the base station are other factor that lower the performance. Nevertheless with bandwidth up to 10Mbit/s using WiMAX provides more then enough bandwidth for most mobile applications. Also AT&T using HSPA+ provides a generous service with an average bitrate of about 5Mbit/s. It is interesting to note that although Sprint and T-Mobile use HSPA for their 3G networks, the comparison shows a significant performance difference, which is probably due to the limitation discussed earlier. Finally, compared to the other access technologies, EDGE provides a very low average bitrate, which is not suitable for bandwidth hungry applications such as video streaming.

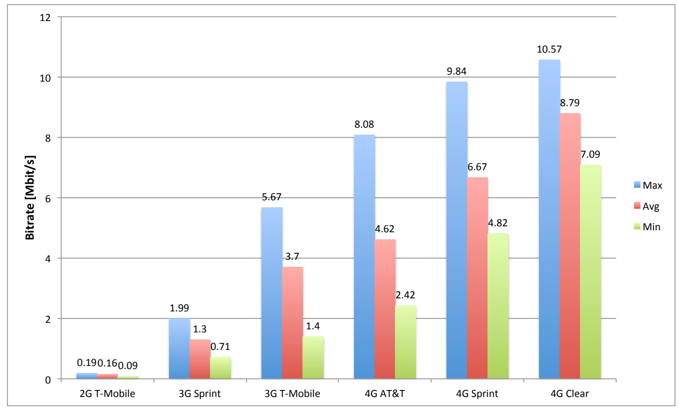


Fig. 1. Download Speed Comparison.

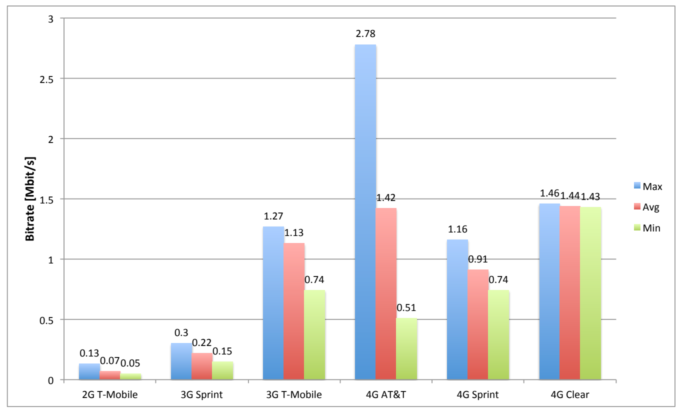


Fig. 2. Upload Speed Comparison.

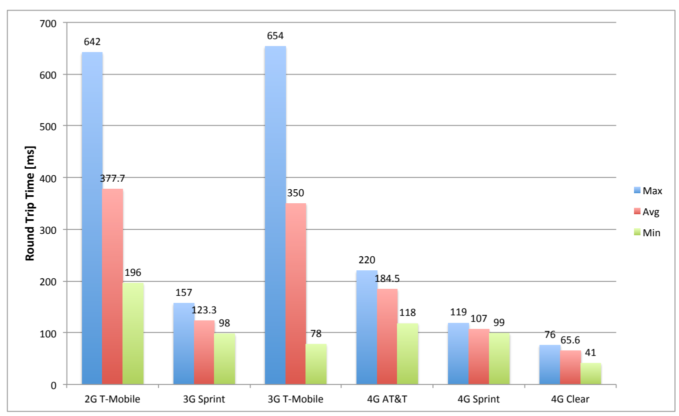
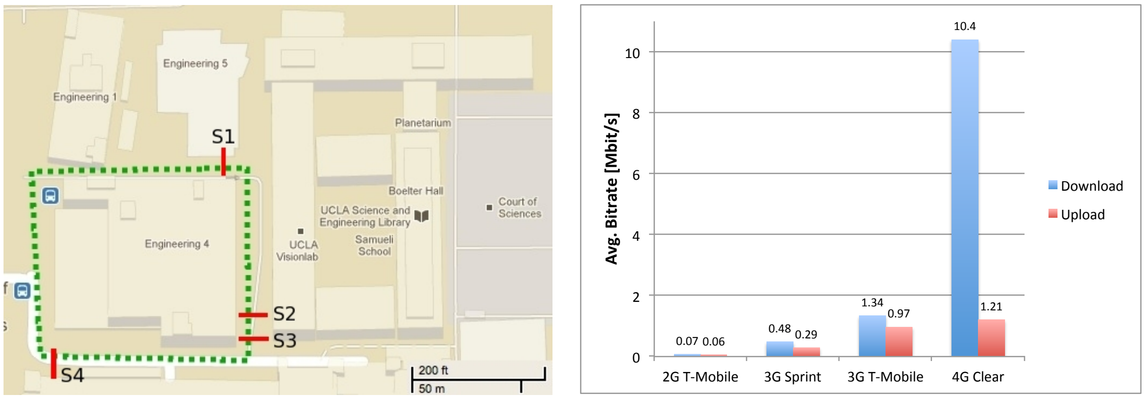


Fig. 3. Round Trip Time (RTT) Comparison.

Figure 2 shows the results for the upload tests. It is interesting to note that the trend is slightly different as compared to the download. Although the two WiMAX operators Sprint and Clear still provide remarkable performances, AT&T with HSPA+ reaches peak uploads of almost 3MBit/s. As most operators consider upload speed as less important (considering the mobile data traffic), the bandwidth is frequently limited. This is clearly the case for Clear where the minimum, maximum and average values are almost the same. On average



(a) Map (b) Average Results

Fig. 4. Experimental setup and average throughput results for upload and download using different access networks.

however, we can see that 3G and 4G technologies have similar bitrates, which are high enough to support the transfers of the much higher download data rates. Here again, the T-Mobile 2G using EDGE provides very low performance compared to the remaining tested technologies.

Finally, the results for the latency tests are depicted in Figure 3. What we measure here is the Round Trip Time (RTT). In other words, the time a data packet needs to propagate to a remote server and back. For our specific scenarios, the results show that the RTT seems to be operator dependent rather that technology dependent. It is true that most to the delay is induced by the operator himself depending on how the data is routed to the outside world (and back). For T-Mobile using 2G and 3G technologies it is clear that there is some room for improvement. The remaining tests show reasonable and comparable delays that have to be expected on mobile wireless networks.

B. Mobile Tests

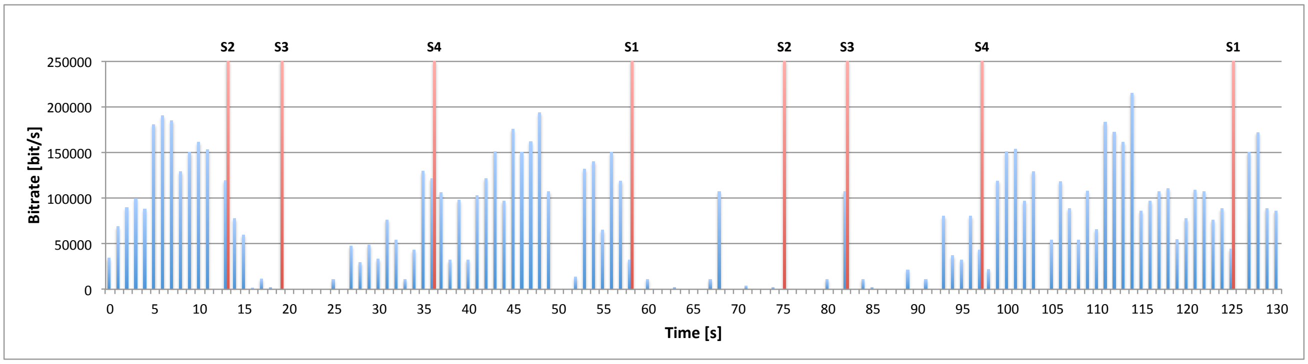
In this section we are going to present the results obtained during our mobile runs. Please note that due to restrictions imposed by some mobile telecommunication operators, not all previously benchmarked networks could be tested. The following services have been tested: T-Mobile 2G, Sprint 3G, T-Mobile 3G and Clear 4G. For every service we tested download and upload capabilities by continuously downloading respectively uploading a random bit stream from a remote web server. For every run, we circled twice around the building block depicted in Figure 4(a). The average bitrate for every tested access networks is shown in Figure 4(b). Compared to the results discussed in Section IV-A, one can clearly see that the 2G and especially the 3G download performance is significantly lower with a bitrate almost divided by three. As expected, Clear 4G using WiMAX provides nearly same performance as during the static tests. This is mainly due to the fact that the modulation scheme used is more robust to mobility compared to the techniques used by previous technologies. Due to the upload limitations, the performance of all the tested networks remains similar as compared to static tests.

Figure 5 presents the detailed results for the download and upload runs using the T-Mobile 2G network. The red lines indicate at what time the different stop signs have been reached (at those locations, the vehicle was completely stopped). Looking at both charts, there is no obvious trend that can be identified. Although the two laps show similarities for the download run, factors such as urban canyons and stops cannot by uniquely identified. One can see that for both runs there are several connectivity holes in which the bitrate drops to very low values, which explained why the average bandwidth is so low.

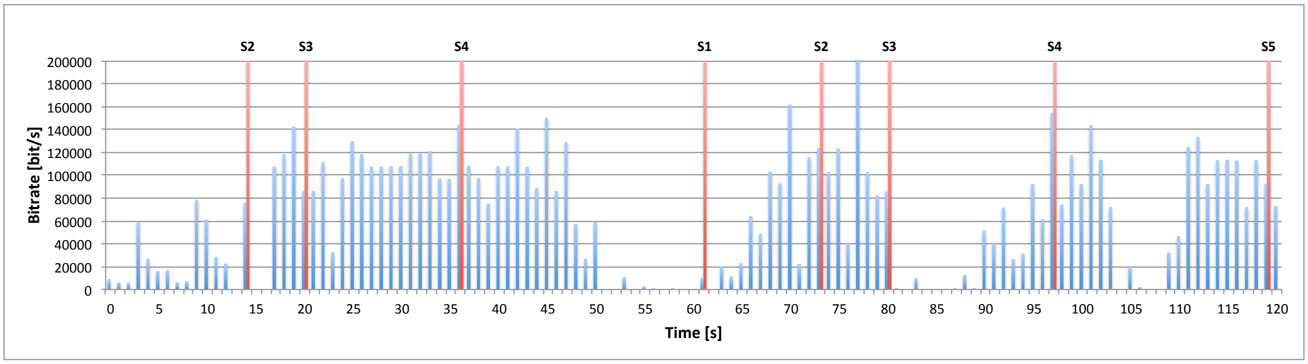
The results of the Sprint 3G runs are depicted in Figure 6. Compared to EDGE, there are far less fluctuations and connectivity holes, however there is still no clear trend that can be extracted from the data. In the upload graph one can see that the bitrate remains far more constant as compared to the download rate. As already mentioned earlier, this is probably due to the fact that the upload bandwidth has been limited by the network operator and thus provides a more stable performance.

Another 3G test, this time using the network of T-Mobile, is shown in Figure 7. Now we can clearly identify a recurring pattern for the download as well as for the upload traffic. We can see that the bitrates are higher between S4 and S1. This behavior can be expected, as this part of the route does not have buildings on both sides of the road. Similarly, the remaining part of the route, which is tightly enclosed by buildings does not allow such high bitrates. It is interesting to note that although this phenomenon occurs, the overall performance of the T-Mobile network is significantly higher compared to the Sprint network. There are several explanations why there is such a difference in performance and shape. The most probable is the location and relative position of the base station. For T-Mobile the antenna might be closer and better oriented providing a better signal in non-obstructed areas whereas the weaker signal coming from the Sprint antenna provides the same moderate service all over the experimental area.

Finally, the results for the Clear 4G runs are shown in Figure 8. Similar as from the T-Mobile 3G tests, the urban canyon can clearly be identified for both download and upload.



(a) Download



(b) Upload

Fig. 5. T-Mobile 2G EDGE bitrate results captured by a moving vehicle.

Nevertheless the overall performance remains spectacularly high with an average bitrate of more than 10Mbit/s while on the move. The mobility factor does not play an important role, as the overall bandwidth is the same as the one recorded during the static tests. Similarly for all the tested networks, the stops did not reveal a noticeable increase of the bitrate. The variation of the bitrate can mainly be explained by the robustness of the modulation scheme and the urban environment.

V. Conclusion

In this study we have benchmarked several mobile network technologies of major commercial operators in the area West Los Angeles. We have identified that the data rates specified in the communication standards can hardly be reached as this would required an ideal tests environment which cannot be reproduced on commercial networks. Our study shows that the mobility itself does not significantly lower the performance of the network. In general one can say that the performance of the network is as good as its initial planning. The strategic number and placement of the base stations are important aspects especially in urban environments. Other factors include, concurrent usage of the shared medium and environmental interference. There is however a significant difference in performance looking at the different technologies. The more recent 3G/4G technologies provide moderate to excellent service as opposed to old but still heavily used 2G EDGE that only provides very low bitrates. Further, consumers should be careful when subscribing to a new data plan. Today, there is no clear definition on what technology hides behind the term *"4G"*. In our study the term 4G was using with three different communication technologies namely HSPA+, WiMAX and LTE which do not have the same performance characteristics. Unfortunately due to contractual obligations, no LTE tests could be performed and are subject of future work.

Acknowledgment

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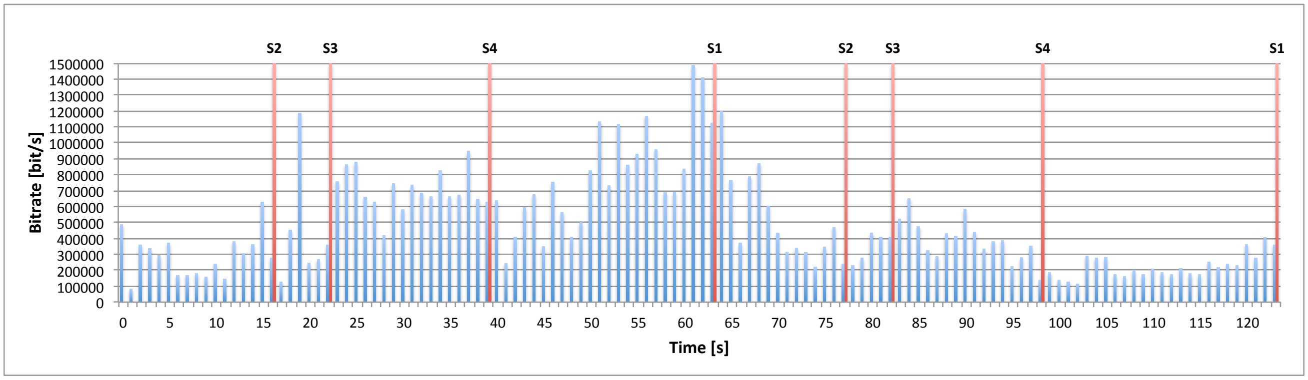
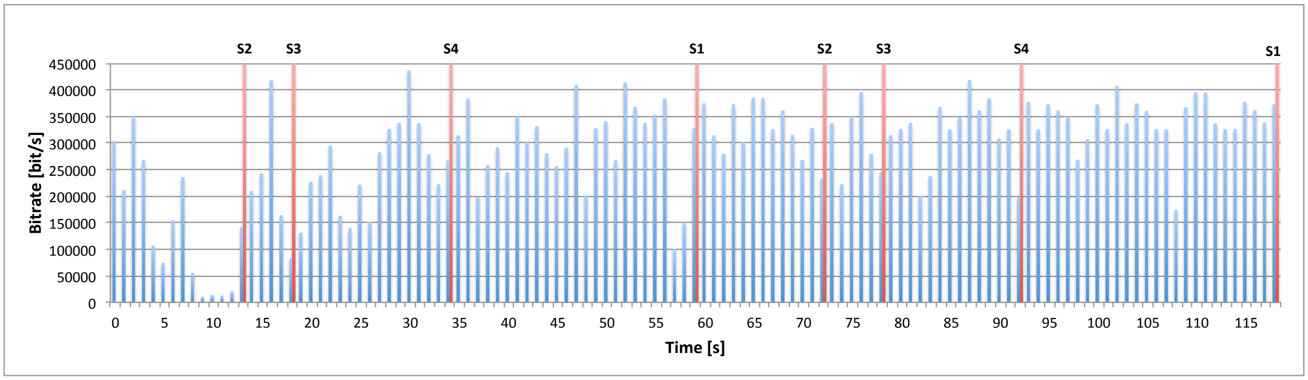
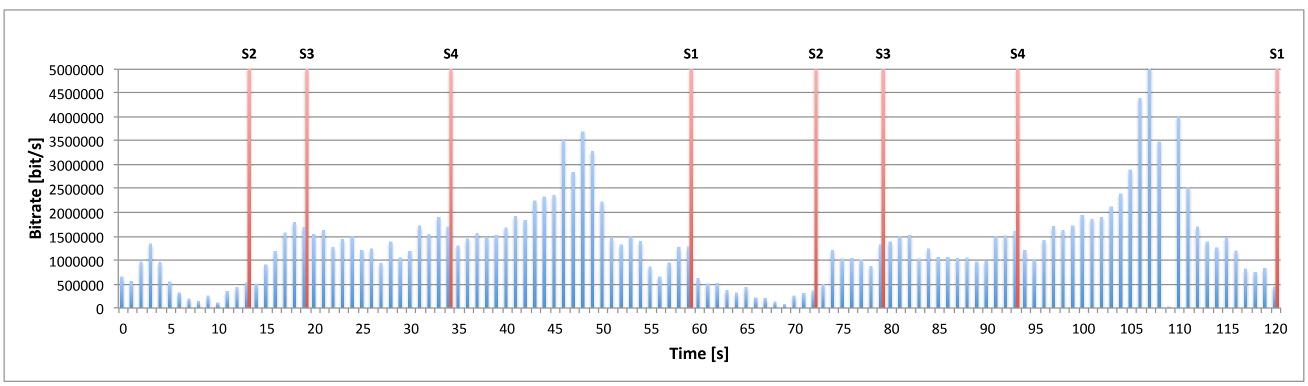


(a) Download



(b) Upload

Fig. 6. Sprint 3G HSPA bitrate results captured by a moving vehicle.



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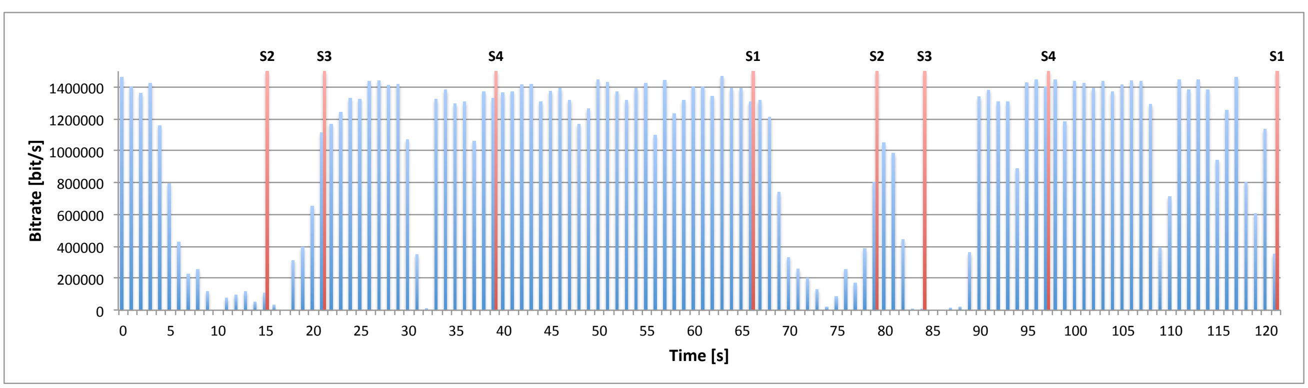

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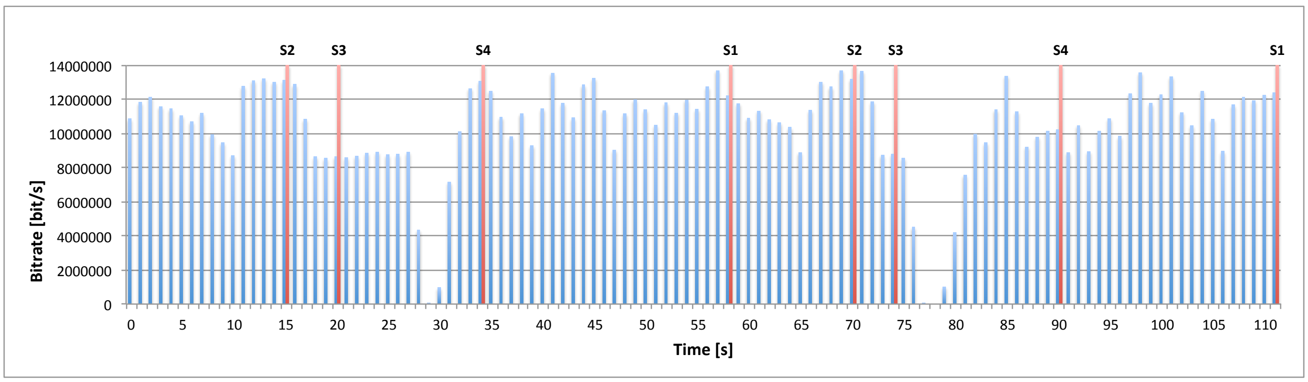
Fig. 7. T-Mobile 3G HSPA bitrate results captured by a moving vehicle.



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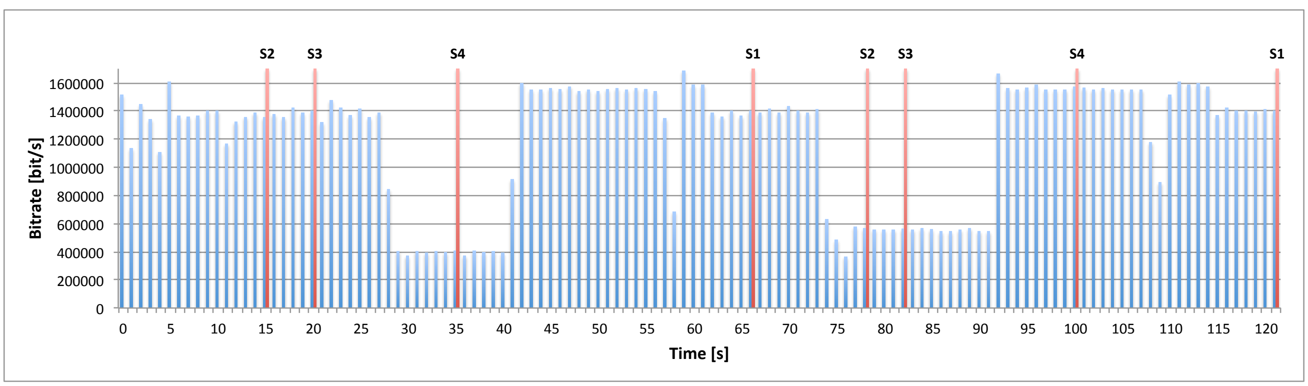

(b) Upload

Fig. 8. Clear 4G WiMax bitrate results captured by a moving vehicle.