IP Impairment Testing for Wireless Mobile Networks

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ABSTRACT

Wireless mobile telecommunications are of growing importance and an enabler for the Internet of Things. Most networks are IP based or moving to an IP based infrastructure, including the latest 4G LTE and the future 5G networks. Understanding and being able to predict the behavior and performance of such networks in various scenarios and conditions is critical. This drives the need to study IP impairments in wireless telecommunications networks and to assess their impact on network and service performance. One method is to emulate/generate IP impairments while observing and measuring their impact on network performance. In this paper the authors analyze the challenges associated with analyzing the behavior of mobile wireless networks. They discuss the importance and benefits of IP impairments testing and mention the high cost of dedicated IP impairment emulators for telecommunications. A flexible and affordable solution is proposed for educational purposes and the study of IP impairments on wireless telecommunication networks.

Keywords: IP impairments, LTE network impairments emulation, network performance.

INTRODUCTION

Wireless mobile telecommunications are of growing importance in all industries and all areas of our daily lives. They are the basis of our connected present reality and in future will offer the key services for the Internet of Things, enabling the massive deployment of smart devices, sensors and nodes (Bahga & Madisetti, 2014). We expect non-stop availability of mobile wireless services, and telecommunication networks need to provide high quality communication services in optimal conditions and stay in service with acceptable quality in sub-optimal conditions. It is vital that engineers and researchers can observe and understand the behavior of such networks, to be able to properly design, engineer and optimize them for the intended applications.

Most of these networks are already IP based or are moving to an IP based infrastructure. This is true for the currently deployed latest generation 4G LTE networks, as well as the future 5G networks. This means that network impairments affecting the performance of services provided over these networks can be analyzed as IP impairments on these networks. But understanding their behavior and performance is a very complex matter since these networks are not homogenous. Mobile wireless communication networks operate in a large variety of environments and deployment scenarios, so they are built on a wide variety of equipments, physical links and interfaces. Different network segments have different resource utilization and loading. There are also multiple layers of virtual links over one physical link (virtual networks, circuits, tunnels, etc.), with the encapsulating layers passing their "behavior" down to the layers below. There are a very high number of possible
combinations of network elements, links and transport mediums that IP packets can pass on their way through these networks.

Understanding IP impairments and their effect on network performance and service quality is a topic of very high complexity. It is often also the key to solving issues related to network and service performance. This is a topic that needs dedicated focus, methods and tools for study. It is also a topic of growing importance, as we move towards a world where everything is connected and 5G mobile wireless communication networks become vital for all of us.

In this paper, the authors present the challenges in analyzing the behavior of mobile networks. We present the importance and the benefits of IP impairment testing. We also discuss the benefits of technical education on this topic. We discuss aspects that hold back IP impairment testing and propose an efficient and affordable implementation of an IP impairment tool. In the end, we present conclusions and recommendations related to IP impairment testing.

**IP NETWORK IMPAIRMENTS**

Real-life commercial networks do not behave in a deterministic way. Impairments in these networks affect traffic packets that are traversing them. The top three IP impairments (Rusan & Vasiu, 2015c) have the most impact on quality-sensitive services (Juluri, Tamarapalli & Medhi, 2015), (ixiacom, 2017): packet loss, latency and jitter.

Packet loss is a measure of the number of packets sent over a network that fail to reach their destination. This can result in noticeable performance issues. In addition, a decrease in throughput is caused by some transport protocols (e.g. TCP (Majumda et. al. 2002),), which have mechanisms to ensure reliable delivery of packets, requiring the retransmission of missing packets. Causes of packet loss may include multi-path fading, channel congestion, in transit rejection of corrupted packets, faulty hardware, drivers, or routing routines.

Packet delay, also known as “latency”, is a measurement of how much time it takes for a data packet to get from one point to another. Although a measurement of zero delay is not seen in production networks because it takes some amount of time for the packet to travel from its source to its destination, a low packet delay number is desired for optimum network and application performance. Propagation, router/switch processing, and storage delays are normal contributors to the expected delay. However, adverse network conditions like queuing delays on the intermediate network elements also contribute to packet delays.

Delay variation, usually referred to as jitter, is the measure of variability of delay values over a period of time. The delay experienced by traffic is not a static value but usually varies due to random events such as fluctuating loads on the network infrastructure. This dynamic nature of network traffic affects the delay that packets experience as they traverse the network. Packets suffering from delay variance will end up arriving at the destination out of sequence or may even be dropped by the receiving devices. This has a negative impact on the performance of some applications, e.g. voice and video.

**CHALLENGES IN ASSESSING THE BEHAVIOUR OF MOBILE WIRELESS NETWORKS**

It is usually very difficult to predict the behavior and performance of a service over a real network, even with a good understanding of the cause and effect chain. Understanding the theoretical
behavior of IP packets when affected by different impairments is a good starting point, but there are many aspects that further complicate real-life scenarios.

First, we need to consider the complex communication schemes of the applications and services themselves: variable bitrates and periodicity, combinations of signaling streams and user data streams, asymmetrical uplink (UL) / downlink (DL), etc. As our expectations and needs grow, the complexity of services and applications also rises. One example that illustrates this well is video calling. In this scenario we see two constant bitrate real time protocol (RTP) (Schulzrinne et. al, 2003) streams for voice, symmetrical in UL and DL, with strict packet periodicity at 20ms. But during no-speech intervals it is possible that voice activity detection (VAD) kicks in and there are no RTP packets at all for certain time intervals, in one direction only or in both directions. Additionally, there are variable high bitrate RTP video streams, not necessarily symmetrical in UL and DL, with variable packet periodicity and bursty traffic. There are also additional real time control protocol (RTCP) (Schulzrinne et. al, 2003) signaling streams, for voice and video: these are low bitrate, have lower transport priority and do not necessarily have a strict periodicity or symmetry. For the sake of completeness we mention that these are all UDP packets in this particular scenario.

Second, there is complexity and variation added by the many possible network elements and their various implementations. The core network (CN) and radio access network (RAN) elements all exhibit their own particular behavior. Often, backhaul network elements are also in unexpected configurations and add their own share of complexity. And even though all these network elements follow industry standards, implementations can vary in their robustness or flexibility, thus adding to the many variables already in place. For a simple example, we can consider a mobile network with sites in densely populated cities as well as in remote mountain areas: the urban sites will have fiber backhaul, while the remote sites on mountains will probably serve very few users and have a microwave backhaul link due to cost considerations. The performance of these two backhaul technologies is very different, with the microwave based backhaul prone to additional performance degradation in bad weather conditions.

The third aspect is related to network usage and loading. This depends on user behavior in relation to mobile network deployment strategies. Preference for certain services, applications or scenarios can vary by culture and geography. They can also fluctuate heavily based on events or specific calendar dates. User density and commute patterns also have a high impact on network resource usage. These aspects are often (or to a certain degree) random and thus difficult to model in simulations. Even when there is periodicity and patterns can be identified, there is a constant struggle to understand those and keep the models up to date: as new services and devices are launched, this alters user behavior patterns or causing them to shift. For example, one only needs to think about placing phone calls on New Year's Eve. Or the first minutes of sales on a Black Friday.

The fourth aspect considers radio conditions. Even though RAN mechanisms try to ensure good link quality and adaptation in all possible radio conditions, it will usually happen that users also experience sub-optimal radio conditions at some point during usage of mobile wireless networks. In this case, all redundancy and retransmission mechanisms on the radio interface can work already at their limits, so there will be impact down to the IP level: increased delay due to retransmissions or, worse, packet loss due to bad radio link quality. If the user is mobile, good and bad radio conditions can alternate during one session as the user moves in and out of good radio coverage.

The above aspects illustrate the challenges and limitations of a purely theoretical approach in studying and analyzing the behavior of mobile wireless communication networks. Such a theoretical study and analysis would be very difficult to conduct, with results that might be very limited in precision and accuracy. It would also be of very limited practical use and plausibility in the case of cutting edge services, applications or even network technologies and elements, since there is limited
experience with these novel elements, especially in scenarios with many users or when interacting with the rest of the network ecosystem.

The first two aspects mentioned above can be measured, modeled, predicted or replicated to some extent. It is possible to generate and simulate various combinations of data streams and links. It is also possible to calculate and/or measure performance parameters of a known configuration of network elements operated under nominal loading. This makes it possible and practical to study specific scenarios in controlled situations and configurations, by emulating the behavior of certain network elements or segments in controlled situations.

The last two aspects mentioned, however, are very difficult to model, replicate or predict. Since they are either random or limited in time, there is a very high effort and cost associated with studying them as they happen on commercial networks or modeling them and keeping complex models up to date. But it can be practical to measure and understand their impact on the IP layer, in best or worst case scenarios. It is then possible to abstract everything down to network impairment models for these best or worst case scenarios - and then model these scenarios by emulating IP impairments in the network (Rusan & Vasiu, 2015c).

Thus, by emulating IP impairments we can overcome some of the challenges associated with the analysis, study and understanding of network and service performance in real networks. Emulating IP impairments can be used for two strategies:

- emulating the behavior of certain network elements and segments in controlled situations,
- simulation of worst and best case scenarios by abstracting the behavior of the communication system to network impairment models.

**BENEFITS OF IP IMPAIRMENT TESTING ON MOBILE WIRELESS NETWORKS**

Studying and testing IP impairments in mobile networks is of high importance. Three groups of stakeholders have a special interest on this topic: network equipment and infrastructure vendors, network operators and third party service providers/application developers.

The challenge for network equipment and infrastructure vendors is to build networks and network elements that meet and exceed their customers' needs and expectations, as well as those of the end users. When developing "world's first" new generation networks and technologies, engineers have to rely on theoretical models and simulations. Valuable findings and insights can be obtained by studying the impact of IP impairments on prototypes or trial networks in early stages of development already. This can help to optimize products or correct unintended behavior as early as possible. Early testing is also important to get an understanding on performance and possible performance issues, before mass deployments begin. It can also help to adjust development strategies, product strategies, as well as planning deployment and optimization strategies.

For network operators it is very important to understand what the capabilities of their deployed networks are. This information is crucial in order to understand what services they can target to offer, at what quality targets and what the associated cost will be for them. Emulating IP impairments and testing for best case, worst case and average scenarios can offer many valuable insights before networks and services are actually deployed. There is also the need to optimize existing networks for new services and applications that will be supported: in this case it is important to understand current network behavior, in order to identify bottlenecks and opportunities for tuning and improvement in the available networks.
Network optimization can also benefit from IP impairment testing. Vendors and network providers often work together for network optimization in order to get the best out of the product / deployed network. The increased complexity of 4G and 5G networks and services, along with the increased density and heterogeneous character of the network deployments, are driving an increase in network optimization efforts. IP impairment testing can provide valuable input information for network optimization tasks. This drives an increased need for such testing in order to determine the focus points for network optimization and what approach would be the most efficient. There is also a cost advantage in conducting such testing by emulating IP impairments, since it brings less of a need to perform extensive and expensive field testing on commercial networks, in possibly inconvenient or expensive test locations and setups.

Application developers and third party service providers can also benefit from understanding the behavior of their products in different scenarios. IP impairment testing can be used to confirm expected performance and desired quality levels for typical network related usage scenarios. Testing against worst case scenarios can help to design services and applications better, increasing their usability and customer satisfaction even in sub-optimal network scenarios, as they become more robust and resilient. This can be an important factor in the success or failure of applications and services, as users are very demanding and have little tolerance with mobile applications that do not work well. (info.dynatrace.com)

RECOMMENDATIONS FOR IP IMPAIRMENT TESTING

There are many benefits of IP impairment testing on mobile wireless networks, for many stakeholders involved in the ecosystem. Trained people and specialized tools are required, but because IP impairment tools can often have a prohibitive cost and are very complex to operate, development in this regard is slow. The cost and complexity are two of the main reasons why IP impairment testing is much less used than expected, given its benefits. This is also why there are few trained engineers on this topic. The very high cost and high complexity of IP impairment tools mean that few people have hands-on experience or access to experimenting with this topic.

Teaching practical aspects on IP impairment testing in technical courses or in technical trainings could partially overcome this hurdle. Hands-on experience and experimenting would be very important and useful for students in this case, especially in contrast to the pure theoretical approach which is only of limited use, as highlighted earlier. Even though the hands-on approach is seldom considered due to the (supposedly) high cost and complexity of IP impairment testing solutions, the authors consider that there are affordable and flexible alternatives available.

The authors implemented one such alternative solution as an affordable and flexible IP impairment tool for 4G LTE network performance evaluation and testing (Rusan & Vasiu, 2015c). We used it for emulating packet loss (Rusan & Vasiu, 2015b) and latency (Rusan & Vasiu, 2015a) and to assess network performance in such scenarios. The main focus when implementing this IP impairment tool was on overcoming the complexity in installation, handling and usage, while also providing an affordable solution that costs many times less than the dedicated systems. The result is a tool that is easy to build and operate, while also being extremely flexible in its use. It can be the right solution for educational, training and demo purposes, as well as for application developers and service providers who wish to evaluate their products. It has no obvious technical drawbacks when comparing to dedicated commercial solutions and can be an attractive solution for all those interested in IP impairment emulation and testing.

The proposed IP impairment tool is a software emulator (Rusan & Vasiu, 2015c). This is a standard approach (injecting IP impairments by using a network emulator) and not a new idea: in 1995 a WAN emulator was already used to evaluate TCP Vegas (Ahn et. al 1995). The solution is based
largely on open source software. It runs on commonly available and cost effective hardware: a mid-range HP workstation PC with two additional server-grade network interface cards (NICs) plugged in. The OS is FreeBSD running an optimized kernel (freebsd.org), to make best use of the available hardware and software. This explains the low cost of the solution. The authors developed a custom interactive user interface for the IP impairment tool (figure 1), to simplify its usage for IP impairment testing (Rusan & Vasiu, 2015c). To further simplify things, it can be controlled remotely and the entire test setup can be operated by a single person. For IP impairment emulation, the machine running the IP impairment tool is inserted on the network link where IP impairments are to be injected (figure 2).

![Figure 1: The IP impairment tool interface while executing a latency test](image1)

![Figure 2: The IP impairment tool connected in a 4G LTE network.](image2)

This IP impairment setup is highly flexible and can be quickly adapted for use in other scenarios, on other networks and technologies that are IP based. It can easily be used for 5G latency testing, for example: its lowest latency setting starts at 0ms and can go up in small increments. This way, an interested party can test an ultra-low latency application that requires 5G technology support for optimal performance, to find its breaking point with good precision and to better understand its tolerance or get a feeling about the user experience when optimal conditions are no longer satisfied.

The IP impairment setup can be used with any network traffic of interest, based on the behavior or application targeted for analysis and testing. It can use both regular traffic (e.g. live or captured traffic on production networks) and synthetic traffic (e.g. lab setup or application test generated traffic), with no particular requirements in this regard. Its general purpose concept, easy to adapt to
use-cases with minimal or no tailoring of existing network interface inputs and outputs, makes it useful for real-world scenarios and even business use, in addition to educational and academic purposes.

CONCLUSIONS

New generation wireless mobile networks are complex systems. Understanding their behavior or the behavior of services running on these networks is very challenging and can often only be correctly assessed by testing in real life scenarios or by emulating relevant aspects of such scenarios.

As technology and industry continues to advance and new developments in the field of communications and networking reach end users, our reality and daily lives get more connected and depend more on the networks that enable these connections. This means that it becomes even more important to be able to understand, evaluate and if possible even predict the performance and behavior of these networks and of their elements, so that the services and functionality provided by them can be optimized and streamlined.

IP impairment analysis and testing can offer many valuable insights on the behavior and performance of networks, network links, network elements, network services and applications. It can even be used to get to a certain level of understanding about end user quality of experience on aspects that can be presented abstractly as a sum of IP impairments. It can be an important tool in the toolset of all stakeholders in the network ecosystem: be it infrastructure or backhaul providers, network element developers, network providers, third party service providers or applications developers. Each of those players could benefit from the possibilities offered by IP impairment testing, allowing them to better understand the behavior of the system and in the end provide better services or products to the end users.

The possibilities offered by IP impairment testing are not fully used at this point. This is due to a combined lack of resources and expertise, high complexity and often prohibitive cost of setting up an IP impairment testing solution.

The authors provide ideas and starting points for those interested to make more of the possibilities offered by IP impairment testing. They recommend a hands-on approach for students or engineers interested on this topic, in order to get experience and a better understanding of the complex relationships and interdependencies in this field. In order to also make such a hands-on approach available and appealing to a broader audience, a solution to the problem of complexity and affordability of tools is provided: the authors presented their affordable, simple and highly flexible implementation for an IP impairment tool. This offers a good starting point for anyone interested to further dive into this domain and it can be adapted and customized for many different technologies and individual interests or needs.

We hope that this analysis offers both motivation and a starting point for improved IP impairment testing for wireless mobile networks. This in turn is a crucial step to better understand how such networks behave, possible scenarios and causes of degradation. We believe that our simple, fast and affordable setup proposal for IP impairment testing opens many possibilities to focus on this area and the related topics. Further research and more experience will lead to more efficient methods and techniques for wireless mobile networks optimization, which are needed for better services and increased user quality of experience.
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