Towards Understanding the Global IPX Network from an MVNO Perspective

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I. Introduction

One of the most critical features of modern mobile networks is the mobility of end devices. Originally designed to support movement between radio cells, it has now evolved into enabling global mobility, allowing devices to connect to networks worldwide. This functionality is called roaming. It enables devices to connect to the networks of arbitrary mobile operators all over the globe, independent of the home network the device is registered with. The roaming functionality is realized through isolated networks with the goal to interconnect different mobile operators and carry signaling as well as user plane traffic between the visited network, and the home network a device is originally registered with. These networks are called IP Exchange (IPX) and GPRS Roaming Exchange (GRX), depending on the mobile generation and type of data to transmit. They are operated and maintained by global carriers such as BICS, Comfone, or Syniverse [1]. This global availability of roaming, while naturally being relevant for human users, is especially critical for global Internet of Things (IoT) use cases. Providers of IoT devices and services may not know where in the world devices will ultimately be deployed. Hence, they need to ensure that devices are able to establish reliable connectivity all around the globe. This use case has risen to a novel type of network operators over recent years. Platforms like the one provided by emnify[1] or Telefonica[2] enable their customers to obtain global connectivity through a single, unified platform. These platforms, realized in the form of Mobile Virtual Network Operators (MVNOs) (emnify) or dedicated platforms on top of existing global infrastructure (Telefonica KITE), provide features custom tailored for machine-type-communication, such as automation, remote configuration as well as centralized monitoring of device states.

In order for these global connectivity providers to achieve a high Quality of Service (QoS) to devices roaming in visited networks all around the globe, they rely on the interconnections provided by the aforementioned mobile carriers. To this end, in this work we highlight a roadmap towards understanding these convoluted, global infrastructures and describe challenges when it comes to the monitoring as well as optimization of network QoS.

[1]https://portal.emnify.com/
[2]https://kiteplatform-api.telefonica.com/

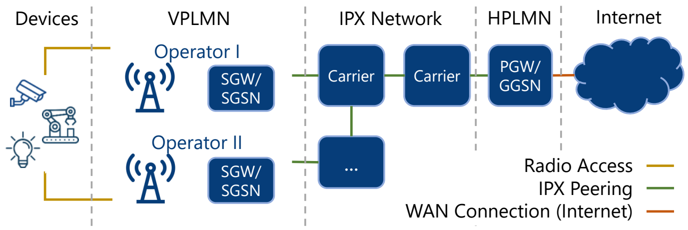

Figure 1: Network architecture from the perspective of an MVNO.

In the following, we provide a brief description of the global architecture of these mobile carriers. We provide initial results with respect to mapping the vast and complex interconnection network enabling global roaming from the point of view of a single MVNO. Finally, we provide preliminary results regarding the quality of service observed under global roaming conditions.

II. The Global IPX Network

In the following, the network architecture of a MVNO is explained. It is a Mobile Network Operator (MNO) with its own core but no own Radio Access Network (RAN). This is solved with roaming agreements with other operators. A simplified architecture can be seen in Figure 1. On the left-hand side, we see the IoT devices connected to the Visited Public Land Mobile Network (VPLMN) of different operators, each hosting an Serving GPRS Support Node (SGSN), in the case of 2G/3G or the Serving Gateway (SGW) in the case of LTE. These communicate to the home network of the device via the IPX network. It consists of multiple IPX carriers and enables mobile operators to exchange data traffic between their networks. Next to the IPX network is the Home Public Land Mobile Network (HPLMN), which hosts the Gateway GPRS Support Node (GGSN) in the case of 2G/3G and the Packet Data Network Gateway (PGW) in case of LTE. Its purpose is to perform GPRS Tunneling Protocol (GTP) decapsulation and connect devices to the Internet.

III. Dataset Description

In order to conduct the analyses presented as well as the future tasks outlined in this work, we are dissecting a number of different data sources described in the following. We both

Table I: Dataset overview.

No.	Data	Type	Location
DT1	User Plane Traces	L2-4, MCC/MNC	Device - GGSN - Internet
DT2	IPX Delay Measurements	Response Times	SGSN - GGSN
DT3	IPX Routing Information	ASN Paths	IPX Network

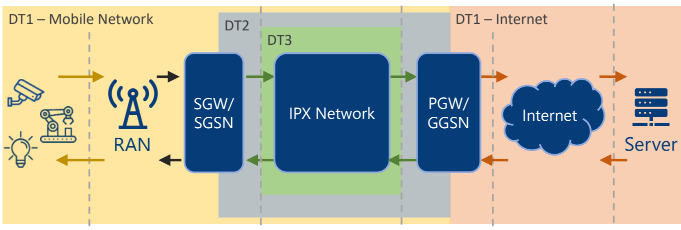

Figure 2: Overview of measurement points for all datasets.

highlight the properties of and the goals we pursue through the analysis of each of the datasets, respectively. Table I provides a summary of the currently available datasets. In addition, Figure 2 highlights the observation point for each of the obtained datasets within the system architecture. DT1 contains user plane traces. These are captured at the PGW/GGSN and the dataset is divided into the mobile network, containing data between the device and the PGW/GGSN and the Internet, containing data between the PGW/GGSN and the application server. DT2 contains IPX delay measurements captured between the SGW/SGSN and PGW/GGSN. Finally, dataset DT3 contains IPX routing information.

A. User Plane Traces

The first and most basic data set consists of traffic traces in PCAP format obtained from performing a full packet capture at the PGW/GGSN of the MVNO (home) network. Contained in the dataset are the flow 5-tuple (source and destination IPs and ports, transport layer protocol) and the packet size. In addition, the traffic captures are enriched with information regarding the currently visited network as well as the Radio Access Technology (RAT). Hence, using the available data, for each flow, we can ascertain delay, jitter, throughput, transport layer protocol, the visited network operator and country as well as if the device is connected using 2G, 3G or 4G/LTE. This allows us to analyze regarding user plane traffic QoS differences between different radio access technologies, countries, operators and continents.

In order to ensure user privacy, we anonymize all source and destination IPs in a way that allows us to consistently track flows throughout datasets, without being able to identify specific IP addresses.

B. IPX Delay Measurements

The second available data source are delay measurements within the IPX network. By actively sending a *GTP Echo Request* from the GGSN/PGW to the SGSN/SGW, we are able to obtain delay values between the home network and the visited network. This allows us to obtain the Round Trip Times (RTTs) induced by the IPX network interconnecting the visited and the home network.

Depending on the level of interconnection, the path these requests take through the IPX network may differ in length. For example, if both the visited and home operators peer with the same IPX carrier, the GTP Echo Request only has to traverse this one carrier to be transmitted among the operator networks. If, however, operators do not peer with the same carrier, packets have to traverse an additional autonomous system before they arrive at their destination, increasing delay, and potentially jitter. Using this data, we are able to isolate delay, jitter and loss that is generated by the IPX network, instead of either the visited or home operator networks.

C. IPX Routing Information

Finally, the third dataset consists of BGP routing information provided by the home MVNO. This information provides insights into the paths taken by packets transmitted from the home network towards various visited networks. This data can be used to obtain the path length, meaning the number of autonomous systems packets have to traverse, towards various visited network operators all around the globe.

IV. Preliminary Results

In this section, we present initial results obtained based on the introduced datasets. For this preliminary study, we evaluate each of the datasets as is, without combining the available information to develop a holistic view on the IPX network and its performance.

A. User Plane Traces (DT1)

Based on the available user plane traces, containing L2-4 data, we are able to determine several QoS metrics. As the monitoring point (GGSN transmits traffic both in direction of the end device and towards the internet, we can separate these two parts of the system and evaluate them separately. The first part (VPLMN) is shown in Figure 2 as *DT1 - Mobile Network* in yellow. This section of the system also contains the RAN. The second part, encompassing the Internet and the application service the device is accessing, is depicted in orange and labeled *DT1 - Internet*.

Figure 3 shows the ECDF of both parts. The x-axis shows the RTT between the Internet and the end device, respectively. The colors indicate five different operators in three different countries. In the Internet facet, it can be seen that for all operators the delays are similar and are at a mean of 25 ms. For the mobile network, we have a much higher delay. Here, we can see differences between the operators. Operator A, C, D, and E have a mean RTT of 80 to 160 ms, whereas operator B has a mean RTT of 520 ms, indicating lower radio performance, core performance or peering towards the IPX network. The identification of the specific issue will be possible in the future, through combination of the available datasets.

Note that other QoS metrics, such as loss and throughput, can also be extracted from the user plane traces, but are omitted here due to space constraints.

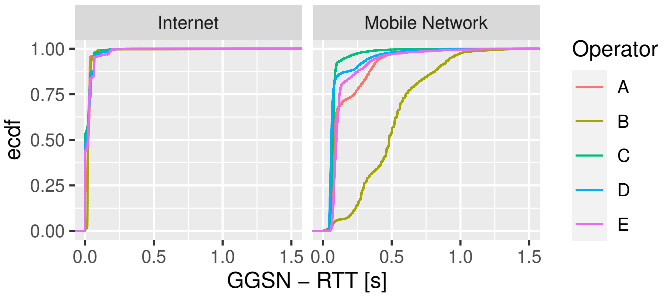

Figure 3: Delay comparison of five different operators for the Internet and the mobile network form user plane traces.

B. IPX Delay Measurements (DT2)

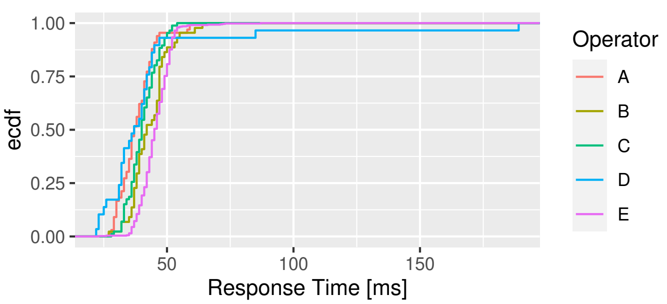

Figure 4: Response time from GTP echo requests.

Based on RTT measurements between SGSN/SGW and GGSN/PGW, we can evaluate the RTT of the IPX network towards specific visited networks. In Figure 4, we can see the ECDF for the RTTs of the same five operators as before. On the x-axis, the response time is shown in ms. The lowest mean RTT of all five operators has operator A with 38.0 ms, and the operator with the highest mean RTT is operator E with 45.5 ms. We can see that operator B, which had significantly higher RTTs towards the mobile network based on user plane traces, does not exhibit significant differences in this analysis. This indicates that the additional user plane delay stems from either radio or SGSN/SGW performance.

C. IPX Routing Information (DT3)

The last dataset contains routing information in the form of AS-paths through the IPX network. Figure 5 shows the distribution of AS-path lengths. The x-axis shows the encountered path length, the y-axis indicates frequency. A similar analysis has been performed in the past by Lutu et al. [1] based on data from Telefónica. Here, we are able to reproduce the data from Lutu et al. from the perspective of an MVNO, hinting at the generalizability of their, and our, observations. With an AS-path length of two, the expected path length dominates the dataset, followed by a length of three and of one. A path length of two hops occurs if the visited network peers with the same IPX carrier as the home network, which, based on our experience as well as the information provided by Lutu et al. should be the majority of cases. Path lenghts of one and

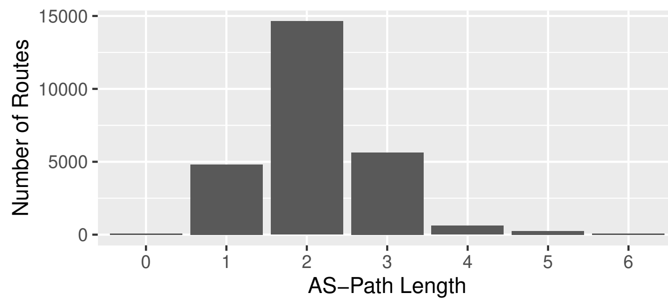

Figure 5: Distribution of AS-path length without prepending.

three occur if two operators either peer directly or do not peer with the same IPX carrier. Paths longer than three hops are to be considered outliers, as IPX carriers are assumed to provide full mesh peering, meaning that each carrier is peering with every other carrier. Hence, the longest regular path between the home network and any visited network is three hops long.

V. Related Work

Till today there are not much research paper about IPX networks. Although Takaaki [2] offers an initial overview of IPX and its technical requirements, the closed nature of IPX has prevented any detailed analysis from being conducted.

Later, an analysis of Lutu et al. [1] provides high-level trends and presents the first in-depth analysis of a commercial IPX-P, discussing its operations and implications for its customers. Furthermore, they analyze a real-world large IPX-P, including its solutions, operational reality, transit provider network, customer base, emerging data communication patterns, and performance enabling the data roaming service [3].

In 2012, a study by Ager et al. [4] analyzing flow measurements from a major European IXP revealed the presence of over 50,000 actively used peering links, highlighting the significant interconnectivity within a single IXP location. This finding emphasized the growing importance of large IXPs, particularly in Europe, with comparable daily traffic volumes to the largest global Tier-1 ISPs and a diverse member base competing with incumbent ISPs. Futhermore, the authors in [5], [6] present a survey that aims to gather and analyze publicly available information about Internet Exchange Points (IXPs) to understand their technical and operational aspects. It highlights the differences among IXPs in various regions, particularly in Europe and North America, while emphasizing the pivotal role of IXPs in shaping and redefining the Internet marketplace, both within Europe and worldwide.

VI. Conclusion and Outlook

This work aims to better understand the global IPX network through the perspective of an MVNO. To achieve this, we identified and captured three different data sources: user plane traces, IPX delay measurements, and IPX routing information. Our analysis of the preliminary results of this data represents an initial step towards achieving our goal of mapping the convoluted global IPX network and advance our understanding of QoS in global roaming deployments.

As the next steps, we plan on capturing a wider range of data points to be ale to develop a holistic QoS model of the IPX network. Then our goal is to unravel the individual steps of the way from the device to the Internet, concerning delay and other QoS parameters. This can be done by combining all these datasets. With the user plane traces (DT1), we cover the way between the end device and the application service on the Internet. Based on measurements from the PGW/GGSN of home network (DT2), we are able to isolate the sources of delay in the mobile network. Finally, based on the routing information (DT3), we are able to develop a map of the IPX network and identify potential issues along the paths of packets on their way from the device towards the open internet.

The overall goal is to better understand the sources of QoS impairments in mobile roaming and to develop models and mechanisms to optimize the quality of this complex ecosystem of interconnected networks.

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