The Internet in Crimea: a Case Study on Routing Interregnum

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***Abstract*—In 2014 the Russian Federation laid claim on Crimea, causing a change of regime and reportedly profound changes in Internet regulation and connectivity in the peninsula. The goal of this study is to introduce tools to monitor this, and similar situations, and to document changes that happened to the Internet in Crimea. This analysis aims at deconstructing a simplistic vision of a geopolitical controversy, by looking into technical arrangements between providers on the international and regional level, and in the context of international sanctions. We employ a multidisciplinary approach, combining sociological fieldwork with Internet measurements to cross-verify our findings. This paper sheds light on some transformations on Crimean networks through an analysis of AS dependencies and semi-structured in-depth interviews with ISPs from the region. We show that network measurements provide an impartial assessment of the effect of politically relevant changes, and allow us to monitor the impact of geopolitical and legal constraints on the networks, such as international sanctions. We believe this work lowers the barriers for interdisciplinary studies that covers Internet infrastructural changes and sets a first milestone to automate such studies in the future.**

I. Introduction

Crimea is a peninsula located at the South of Ukraine and West of Russia. Previously administrated by Ukraine, the Russian Federation laid claim on Crimea in 2014. Amongst others things, it caused changes to the way the Internet was wired, for an estimated 2.3 million people living in Crimea. Until 2014, access of Crimeans to the rest of the Internet was predominantly handled through Ukrainian networks, held to Ukrainian law and oversight. But after March 2014 Russian Internet regulation frame, with its legal and technical constraints, had to be applied to Crimean networks. Although big infrastructural projects were quickly put in place by the Russian government in the region, such as construction of submarine cables, it took three years for Crimean Internet Service Providers (ISPs) to complete the transition.

Crimea serves as a relevant case study on the potential for Internet choke points, regional Internet structure, and a case of geopolitical interest. While the situation in Crimea opposes two sides, we look at this case from a neutral perspective on Internet governance, Science and Technology Studies (STS), and network measurements. Our research is an interdisciplinary study of the slow infrastructural and legal transition in Crimea, providing insights into Internet changes in disputed areas. We combine network measurements with sociological fieldwork to cross-verify our findings. Our ambition is to show methods in both fields applied to the same phenomenon, so we build confidence that these methods can be applied to future studies, even if one or the other angle is missing.

Our study relies on interviews with ISPs from the region (Section II) and a longitudinal analysis of routing changes using BGP data (Section III-B). We propose an adapted AS Hegemony metric to quantify the AS dependency of a geographical area and monitor regional routing changes, such as the substantial routing changes we document for the Internet in Crimea. We also release our dataset and accompanying monitoring tool in order to assist the research community in studying and documenting singularities in the Internet routing infrastructure.

Overall this paper makes several contributions, we demonstrate the way network measurements can provide an impartial assessment of the effect of politically relevant changes. Contrary to the global Internet flattening [3], [7], [6], we demonstrate that the topology in Crimea evolved towards a peculiar structure with a distinctive choke point. We also further the understanding of the impact of geopolitical and legal constraints on the networks, such as international sanctions, and backup qualitative reports with quantitative network measurements. Finally, we provide processed data and monitoring tool in order to ease the process of similar studies.

II. Internet in Crimea

For the sociological part, 45 semi-structured interviews of 1 to 2 hours have been conducted between December 2017 and May 2018 with relevant actors: ISPs from Crimea and Ukrainian mainland; journalists and human rights defenders working in the area; members of the Ministry of Communications of Ukraine; digital security trainers working in the region. We have anonymized all our interviews using a security protocol approved by the Research Ethics Board of the University of Toronto and the Citizen Lab, and we are not allowed to make these interviews publicly available. Semi-structured in-depth interviews consists in interactive exchanges with interviewees that may diverge from the planned questions and raise unexpected findings. The interviews data is then analyzed to find pertinent patterns and themes for our research study. This approach and the relatively low number of respondents, however, prevent us from deriving relevant statistics across all interviews as it is usually done with survey interviews.

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In addition, a selected list of forums and group chats of Crimean, Ukrainian and Russian Internet service providers and end-users was analyzed focusing on debates around the impact of Crimean controversy on the Internet service quality and price.

We tracked the details of the infrastructure transitions between March 2014 and July 2017, using interviews, press analysis, as well as confirming key events with network measurement analysis. Below we present a summary of the events that had an impact on Crimean Internet. The key events are also depicted in Figure 1, which allows for visual correlation of the findings in the field study with Internet measurement results.

Background. Crimea, a peninsula with mountain regions having poor connectivity, was heavily dependent on the Ukrainian mainland for supplies, from water and gas to electricity and communications. Russian control of Crimean information infrastructure followed a "soft substitution" model and took about three years. This particular temporality can be explained by strong dependencies on Ukrainian infrastructure, which would make it impossible for Russian Federation to substitute all necessary services at once, without having an important period of disruptions, shutdowns and resulting indignation among Crimean population. The geopolitical status of Crimea as a disputed area and the resulting sanctions from the US and the EU enforced the development of a grey market of Internet service, including controversial collaborations between Crimea and the occupied territories of Lugansk and Donetsk. Progressive centralization of routing paths and monopolization of Internet Service market in Crimea facilitated control over Crimean networks. Consequently, quality and speed of the Internet connection degraded, while costs of Internet services for end-users became higher.

Ukrainian ISPs left Crimea. Crimea was associated with the Russian Federation after the referendum held on March 16th, 2014. As a result, Ukrainian telecommunication companies started to leave the peninsula and Russia acquired Ukrainian Internet and telecommunication infrastructures. By December 2014 most of Ukrainian telecommunication companies have left Crimea and Ukrainian ISP's licences end.

The Kerch Strait Cable. The Russian state-owned telecommunications company, Rostelecom, announced on April 25th 2014 the completion of a 110Gbps submarine link from Russia to Crimea and said the service will be offered by Miranda Media, Rostelecom's local agent. Miranda Media's main ASN (AS201776) is registered on July 15th, 2014, and first seen in BGP as an upstream provider for Crimean networks on July 24th. An interviewed ISP still operating in Crimea, explains: "*The Kerch Strait cable was used first of all for voice communication, they needed special communications. The traffic capacity of this cable was rather weak for commercial communications*". Therefore, at that time Ukrainian fiber was kept as a backup option and we were told that: "*routes through Perekop (Ukrainian cable) were cheaper and faster than the undersea connection via Kerch strait*". Crimean providers were reluctant to use the new Kerch Strait cable, as it would imply loss of speed and quality of Internet connection, would require additional technical and legal arrangements, and would increase the costs for ISPs and end-users. Moreover, Crimean World of Tanks players were among the first to complain about speed loss on dedicated forums and the price for Internet in Crimea has inevitably raised in 2015.

Internet De/Consolidation. On May 2016 Russia started the construction of a second Internet cable that reuses Kerch bridge infrastructure and is connecting Crimea to an exchange point in Rostov, hence consolidating Crimea's connectivity to Russia. This cable is reportedly first used in July 2017.

A year later on May 2017 Ukrainian president orders to block access to popular Russian platforms such as the online social media vk.com, the mailing service mail.ru, and the search engine yandex.ru. On May 31st, Crimean users complain about Ukrainian blockpages when trying to access these websites. This attracts public attention to the fact that Crimean ISPs are still connected to upstream Ukrainian networks. Then, the summer of 2017 is marked by a big wave of pressure on Ukrainian ISPs and Ukraine stopping to provide traffic to Crimea (allegedly on July 12th, 2017).

III. Internet measurements

We now expose our approach to measure topological changes in Crimea from network data. This analysis consists mainly of identifying ASes operating in Crimea (Section III-A) and monitoring the ways these networks connect to the Internet (Section III-B) before, during, and after the transition.

A. Locating ASNs in Crimea

As Crimea is a disputed area, it is challenging to identify which ASNs were operating from within the peninsula, especially given that the country codes for these ASNs differ and have changed over time (RU, UA, or "Other").

In order to find ASNs in Crimea we first looked at RIPE Atlas probes active in Crimea and verified if they corresponded to a commercial ISP using Whois and searching on dedicated user forums or official websites of these ISPs (if relevant). Then, we looked at all the upstreams of these ASNs and identified those located in Crimea. Second, in February-April 2018 a set of network measurements was conducted on 8 Crimean networks using OONI probe for Android and iPhone by a group of testers in the region [4]. This second set of ASNs and their upstreams were also cross-verified using qualitative methods (forums, interviews). Through this first research we identified the biggest upstreams in the area, Miranda Media and UMLC, as well as two biggest Crimean ISPs, CrimeaCom South and CrelCom. This first part of the analysis resulted in a list of 80 ASNs. After that, we have retrieved from BGP data all downstream networks of Miranda Media and cross-verified the two lists. Finally, we manually checked the list and removed three ASNs that were present at Crimea IX but operated mostly outside of Crimea.

The above steps produced a list of 111 ASNs that were active between 2012 and 2019. This number is surprisingly high, but a closer look at each AS reveals that many of them

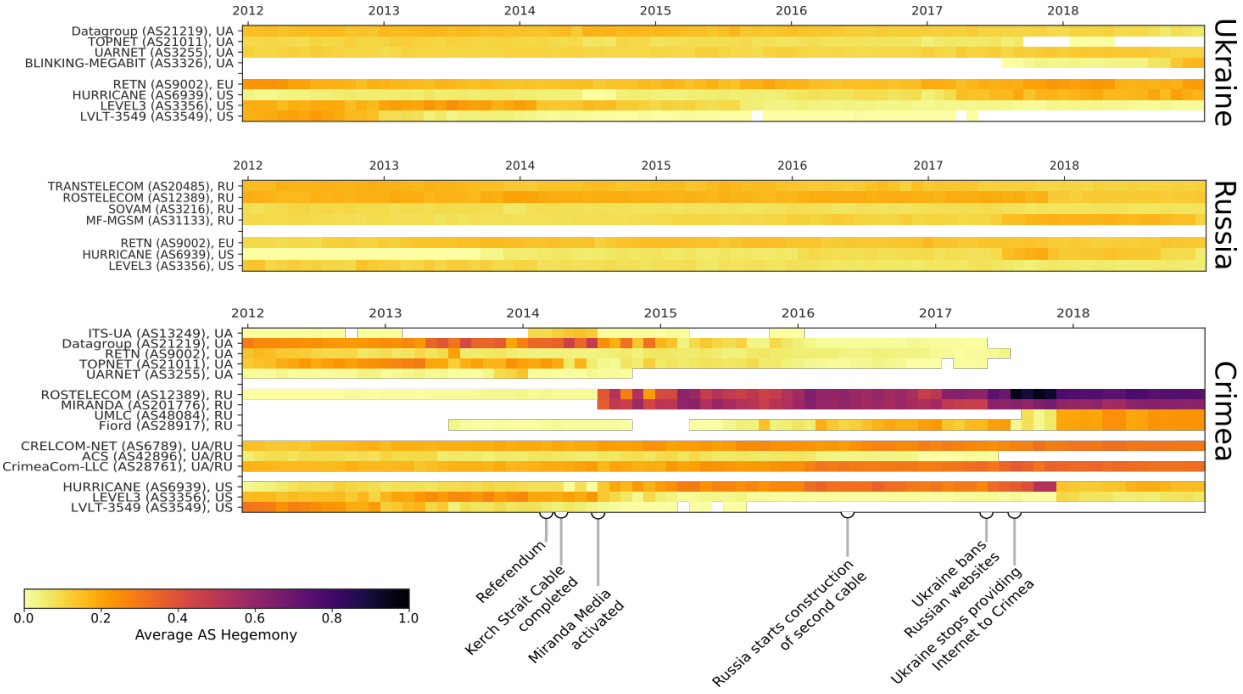

Fig. 1. Average AS Hegemony for networks located in Ukraine, Russia, and Crimea. High AS Hegemony scores reveal networks that are central to reach a region.

are managed by small local businesses, or individuals, and about half of them announce only one or two IPv4 prefixes, usually a /24 or /23.

B. Network dependencies

To identify the main transit networks providing Internet to Crimea, we estimate the AS dependency of Crimean networks with BGP data and the AS Hegemony metric [6]. AS Hegemony, $H_{ASx}(ASy)$, quantifies the likelihood of ASy to lie on paths towards ASx. These values range from 0 to 1; $H_{ASx}(ASy) = 1$ means that ASy is commonly seen on all paths bound to ASx, while values close to 0 means that ASy is rarely seen on these paths. Following the BGP peer diversity results presented in [5], we collected data from two RIS (RRC00, RRC10) and two Routeviews (RV2, LINX) collectors which account for more than 100 BGP full-feed peers. Then we computed AS Hegemony values for all globally reachable ASes on the 15th of each month from January 2012 to December 2018. Our results are made publicly available[8] so that researchers may use it for similar longitudinal AS dependency analysis.

To compute AS Hegemony scores for a geographical area, we merge results obtained for all origin ASNs located in this area. For Crimea we employ the list of ASNs compiled in Section III-A, retrieve the AS Hegemony scores for each of these ASes and compute the average AS Hegemony scores. Average AS Hegemony also ranges from 0 to 1, but it conveys the usual network dependency across ASes. Values close to 1 stand for transit ASes commonly seen on paths towards all ASes in the area. Values close to 0 could represent a transit AS that is, either, rarely seen in paths to all ASes in the area, or, heavily employed by only a handful of ASes.

As a reference we also compute the average AS Hegemony for all ASes registered in Ukraine and in Russia (excluding Crimean ASNs). The benefits of comparing these results to the ones obtained with Crimean ASes are twofold. First, it constitutes a control group for our experiments with Crimean ASes hence assesses the adequacy of AS Hegemony for this study. Second, identifying major transit networks in these two countries helps us to understand the transition in Crimea and changes in network dependencies.

Ukraine. As shown in Figure 1, the dependencies measured for Ukrainian ASes are stable from 2012 to 2018. The main observed change is the decrease of TOPNET from 2017 and the rise of Blinking Megabit at the same time. TOPNET peeringdb entry[12] mentions that AS21011 is "slowly migrating to AS3326". These ASes are both owned by Datagroup, whose main AS is also one of the main transits for Ukrainian ASes. Consequently, from these results we found that the dependencies to Ukrainian networks are mainly Datagroup and UARNET. Other significant dependencies are large international ISPs, such as RETN, Level(3), and Hurricane Electric. Since RETN network is primarily deployed in East Europe and Russia [13], this network is observed as a main transit for both countries. We also noticed that RETN was registered from May 2012 with the country code UA but it has changed in July 2018 to EU.

Russia. Similar to Ukraine the dependencies of Russian ASes are stable over the whole measurement period. Dependencies to national ASes consist mostly of two state-owned

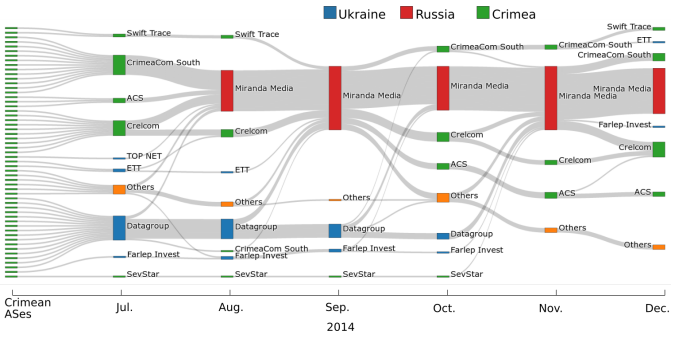

Fig. 2. *Adoption of Miranda Media.* Main dependencies of Crimean ASes from July to December 2014. Left nodes represent Crimean ASes, other nodes are the main dependencies of Crimean ASes at different points in time. Only the highest dependencies are shown, in the case of a tie the closest AS to Crimea in the AS paths is selected.

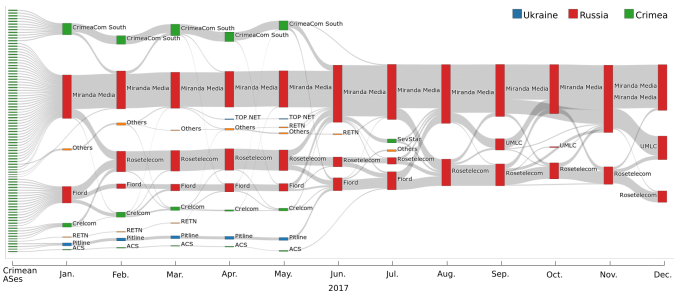

Fig. 3. *End of the Transition.* Main dependencies of Crimean ASes in 2017. Left nodes represent Crimean ASes, other nodes are the main dependencies of Crimean ASes at different points in time. Only the highest dependencies are shown, in the case of a tie the closest AS to Crimea in the AS paths is selected.

ISPs, Rostelecom and Transtelecom, as well as two other major Russian ISP, MegaFon (AS31133) and SovAm/VimpelCom (AS3216). Russia has similar international dependencies to Ukraine (i.e. RETN, Level(3), and Hurricane Electric).

Crimea. Unlike Ukraine and Russia, the AS dependencies for Crimean ASes are drastically changing. In 2012 and 2013 dependencies consists in the ones observed for Ukraine along with dependencies on local Crimean ISPs (CrimeaCom, CrelCom and ACS) and a weak dependency on Rostelecom. These results reveal the role of local Crimean ISPs as a proxy to larger Ukrainian and international ISPs. 2014 is marked by a significant dependency increase for a new AS, Miranda Media, and its parent company, Rostelecom. At that time, numerous AS paths feature the same pattern, the paths originate from Crimea go through Miranda Media and then Rostelecom. This routing change has significantly reduced the number of paths transiting through Ukraine, this trend continues until mid-2017 where we see no more path going through Ukrainian ASes. From 2015, another Russian ISP, Fiord, is also becoming a common transit for Crimea and similarly to the Miranda Media/Rostelecom couple, from August 2017 Fiord connects to Crimea via UMLC.

In summary, the topology of Crimean networks has evolved to a singular state where paths bound to the peninsula converges to two ISPs (Rosetelecom and Fiord) located outside of Crimea. The transition was marked by two major events, the appearance of Miranda Media in 2014 and the end of transit via Ukraine in 2017. We investigate in details these two phases in the following two sections.

C. Adoption of Miranda Media

The creation of Miranda Media is the first evident initiative from Russia to consolidate Crimean connectivity. As depicted in Figure 1 multiple Crimean ASes have indeed switched to Miranda Media as soon as it is made available in 2014. To understand the adoption dynamics of Miranda Media, we detail the main AS dependency of Crimea from July to December 2014.

We found that 55 out of the 78 Crimean ASes that were active in 2014 had a strong dependency to Miranda Media (i.e. $H > 0.5$) for at least one of the monitored dates in 2014. Figure 2 depicts these 55 ASes (left nodes) and their major AS-dependency in 2014 (all other nodes). If an AS depends equally on multiple networks we assign its major dependency to the closest non-Crimean AS in terms of AS-path. For example, networks with dependencies $H = 1$ for CrimeaCom South, Miranda Media, and Rostelecom are classified as Miranda Media.

On July the monitored dependencies are similar to what we observe for Crimea since 2012, but on the following two months we acknowledge significant changes as Miranda Media appears on paths to CrimeaCom South, CrelCom, and ACS customers. Thus, by connecting to central Crimean ISPs, Miranda Media becomes the main transit network for Crimea in a very short time frame.

From October 2014, however, we observe new dependencies to the three main local ISPs (Figure 2). This is because these networks are again seen on paths with Ukrainian upstreams instead of Miranda Media. Operators informed us that Ukrainian ISPs were sometimes preferred because of the higher cost and degraded quality experienced with Miranda Media.

Miranda Media also attracted numerous customers from Datagroup, but unlike the examples described above the adoption is slow and steady. Every month a few Datagroup customers switch to Miranda Media, thus the number of Crimean customers for Datagroup significantly reduced by the end of 2015.

In Summary, the arrival of Miranda Media and connections to key ISPs had an immediate and significant impact on Internet routing in Crimea. We found, however, that networks had to maintain paths to Ukraine as Miranda Media capacity was not sufficient. Also about a third of Crimean ASes (23 out of 78 ASes active in 2014, not shown in Figure 2) did not commit to Miranda Media in 2014 and kept the majority of their paths going through Ukrainian ISPs.

D. End of the Transition

Ukraine claimed that it stopped providing Internet connectivity to Crimea on July 2017. To understand the connectivity

of Crimea before and after this key event, we also investigate the AS dependency changes for Crimean ASes in 2017 (see Figure 3).

From January to May 2017 we observe only four ASes relying mainly on Ukrainian ISPs (see Pitline and TOP NET in Figure 3). At that time Miranda Media/Rosetelecom and Fiord provide Internet to a large fraction of Crimean ASes. However, the three main Crimean ISPs (CrimeaCom South, CrelCom, and ACS) still have connections with Ukraine.

On January, CrimeaCom South relies mainly on Fiord ($H = 0.8$) and a bit on an Ukrainian ISP, WNET ($H = 0.07$). In the following months a few paths go through Miranda Media, paths through WNET completely stop on May 23rd. Then on July 19th, 08:00 UTC, all paths are suddenly starting to go through Miranda Media (H=1.0).

ACS relies equally on Dataline and Miranda Media from January to June. On June 5th, Dataline disappear from ACS's paths, replaced by CrimeaCom South. Then, ACS follows the same changes as CrimeaCom South from June 2017.

In early 2017 CrelCom relies mainly on Russian networks, Fiord ($H = 0.65$) and Miranda Media ($H = 0.25$), but later it featured two drastic routing changes. On February almost all paths to CrelCom start transiting through Rostelecom ($H = 0.95$). Then, On July 19th 11:30 UTC, 2.5 hours after CrimeaCom South switched entirely to Miranda Media, all paths to CrelCom also start transiting via Miranda Media. At that time Fiord is apparently not used anymore in Crimea and the pair Miranda Media/Rostelecom is dominating Crimean connectivity (Figure 3, August 2017).

A month later, on August 22nd 2017, UMLC starts providing connectivity to Crimea. At first UMLC appears only connected to CrelCom in Crimea and Fiord in Russia, we measure about 20 Crimean ASNs with paths going through CrelCom, UMLC, and Fiord. Consequently, Fiord comes back by the end of 2017 as a major provider to Crimea via ULMC (see also Figure 1). Afterwards, UMLC is directly connected to others Crimean ASes but seems to use exclusively Fiord as upstream provider, thus forming the UMLC/Fiord pair depicted in Figure 1.

Overall, we observe in 2017 routing changes that lead to a particular topology with a choke point composed of the two pairs, Miranda Media/Rostelecom and UMLC/Fiord (Figure 3). This topology is substantially different from the diverse connectivity observed before August 2014 (Figure 2).

IV. Community Contributions

This work has led to the development of tools and datasets that go beyond the study of the Crimean Internet. The methodology presented in Section III-B to monitor the network dependency of Crimea is applicable to any geographical area. In this section we present our dataset of historical AS Hegemony scores and the accompanying monitoring tool. Both are made publicly available [8], [9] so that anybody can reproduce our results or explore other distinctive Internet routing events.

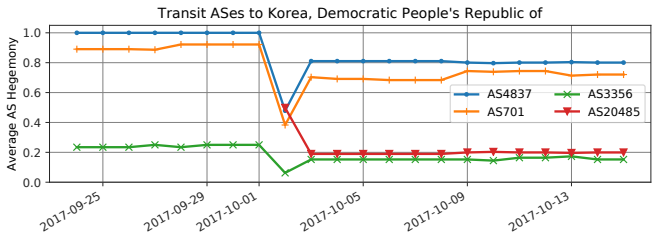

Fig. 4. AS dependency of North Korea during the activation of a new Internet connection with Russia.

A. Dataset: Historical AS Hegemony

The produced dataset contains AS Hegemony scores on the 15th of each month from January 2012 to December 2018, it is indexed by ASN, and made available through a REST API. This database enables prompt longitudinal analysis of network dependencies by avoiding the burden of downloading and processing the tens of Gigabyte of corresponding BGP data.

AS Hegemony scores are computed for each globally reachable AS. Thus one can request data for a single AS, but smaller granularities, for example an IP prefix, are not yet available. The database is accessible through a REST API, a query consists of a set of ASNs and a date range, and the results are presented in JSON format.

B. Tool: Measuring Geographical Areas AS dependency

To ease the access to the above dataset we also provide a tool that queries, aggregates, and monitors AS dependency for a set of selected ASes. This tool reproduces the methodology described in Section III-B.

The set of selected ASes depends of course on the studied geographical area and related events. This can be a challenging task, for Crimea we had to manually find and cross-verify a list of ASes operating from the peninsula (see Section III-A). But for a country-wide analysis, the tool accepts a country code and retrieves a list of the country's main networks from APNIC estimates [1].

Using APNIC population estimates, we can also weight AS Hegemony scores by the number of end-users ("eyeballs") in selected ASes. We plan to investigate this in future work. We didn't do this for the analysis of Crimea, because of the large number of very small ASes and lack of historical data.

C. Examples

To illustrate the value of the released dataset and tool, we present two simple examples of country AS dependency. Each example can be easily reproduced with a single command line. Figure 4 and 5 are obtained by setting our tool to plot the most dominant transit ASNs for North Korea and Iran.

a) Democratic People's Republic of Korea:: The first example represents the network dependency of North Korean Internet during September and October 2017. This is an elementary example as only one AS is operated in that country (AS131279). Figure 4 depicts the AS dependencies for this

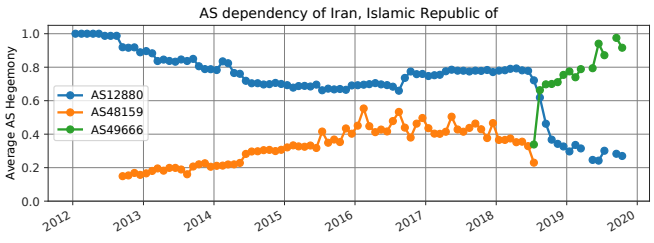

Fig. 5. AS dependency of Iranian eyeball networks. The country three main AS dependencies are managed by a Government-owned telecommunications company.

network. Before October all the BGP paths to that AS transited through China Unicom (AS4837), but this changed on October 2nd when a new connection via a Russian ISP (TransTeleCom, AS20485) was advertised. This simple example illustrates the relations between networks in the three countries and the apparent intent to improve Internet connectivity for North Korea [14].

b) The Islamic Republic of Iran:: The second example explores the network dependency of Iran. Previous studies [2], [18] have shown that Internet traffic in that country is under control of a state-owned ISP called the Telecommunication Company of Iran (TCI).

Figure 5 depicts the network dependencies of Iranian eyeball ASes, 61 in total, from 2012 to 2019. All BGP paths in 2012 are going through one of TCI's ASes, AS12880. From 2013 we observe that some of the paths are transiting via another AS managed by TCI, AS48159, and in 2018 both have been mainly superseded by again another TCI network, AS49666. These results complement previous observations, we confirm the presence of a bottleneck that may facilitate censorship and advert new insights into the time evolution of that bottleneck. The relationships between the abrupt routing change in 2018 and the numerous geopolitical events that happened in the region at that time are worth investigating but left for future work.

The presence of such topological choke points are noteworthy for both Internet censorship and Internet resiliency studies. We believe the released tool and dataset are valuable contributions that enable the research community to better monitor and document these topological singularities.

V. Concluding and Ethical Remarks

In this paper we employ a multidisciplinary approach to document the transition of the Internet in Crimea from 2014 to 2018. This long process involves different technical, commercial, and legal challenges between providers at the international and regional level. We show the use of Internet measurements as an impartial and effective way to assess the effect of politically relevant changes.

We recognize exposing routing policy changes might put network operators at risk, specifically in cases of government orders, hence we make sure to mitigate this risk as much as possible. We made contact with many of the people involved, who shared their view about this with us, which we can summarize as that our research is not putting people in danger, because what we report on is locally already considered common knowledge. Our research backs up this local knowledge with neutral and reproducible network data analysis. In addition, we quantify information that is qualitatively available via a list of media publications.For example the arrival of Miranda Media from 2017 is documented on Dyn blog [10], [11]. The acquisition by Russia of the Ukrainian telecommunications infrastructure was reported by Telegeography [15], [17], [16]. Our assessment is that the ethical risk of this work is minimal while the benefits of going from qualitative information to neutral and reproducible network data analysis is substantial.

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