The Resiliency of the Ukrainian Segment of the Internet

Alex Semenyaka, RIPE NCC
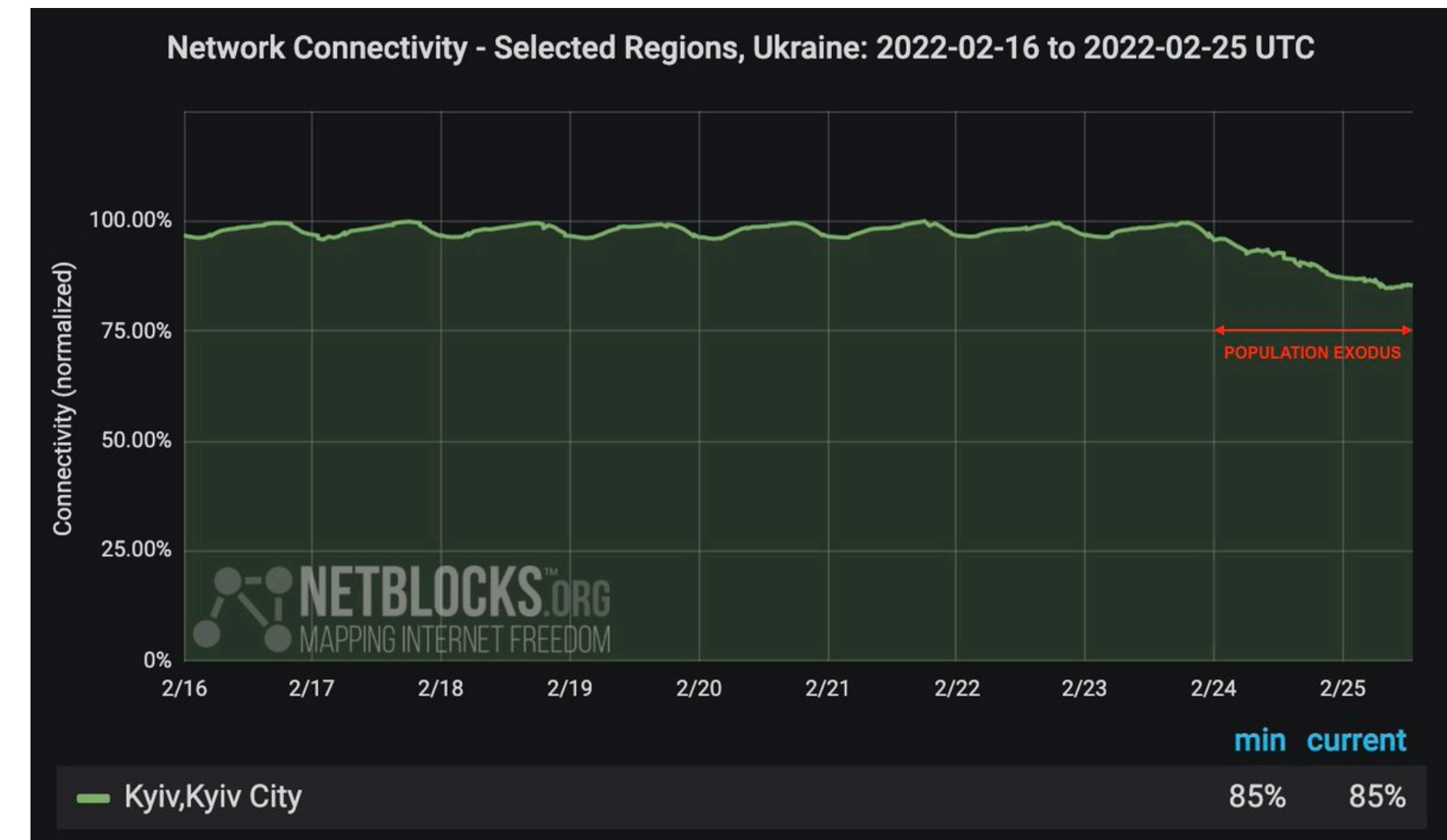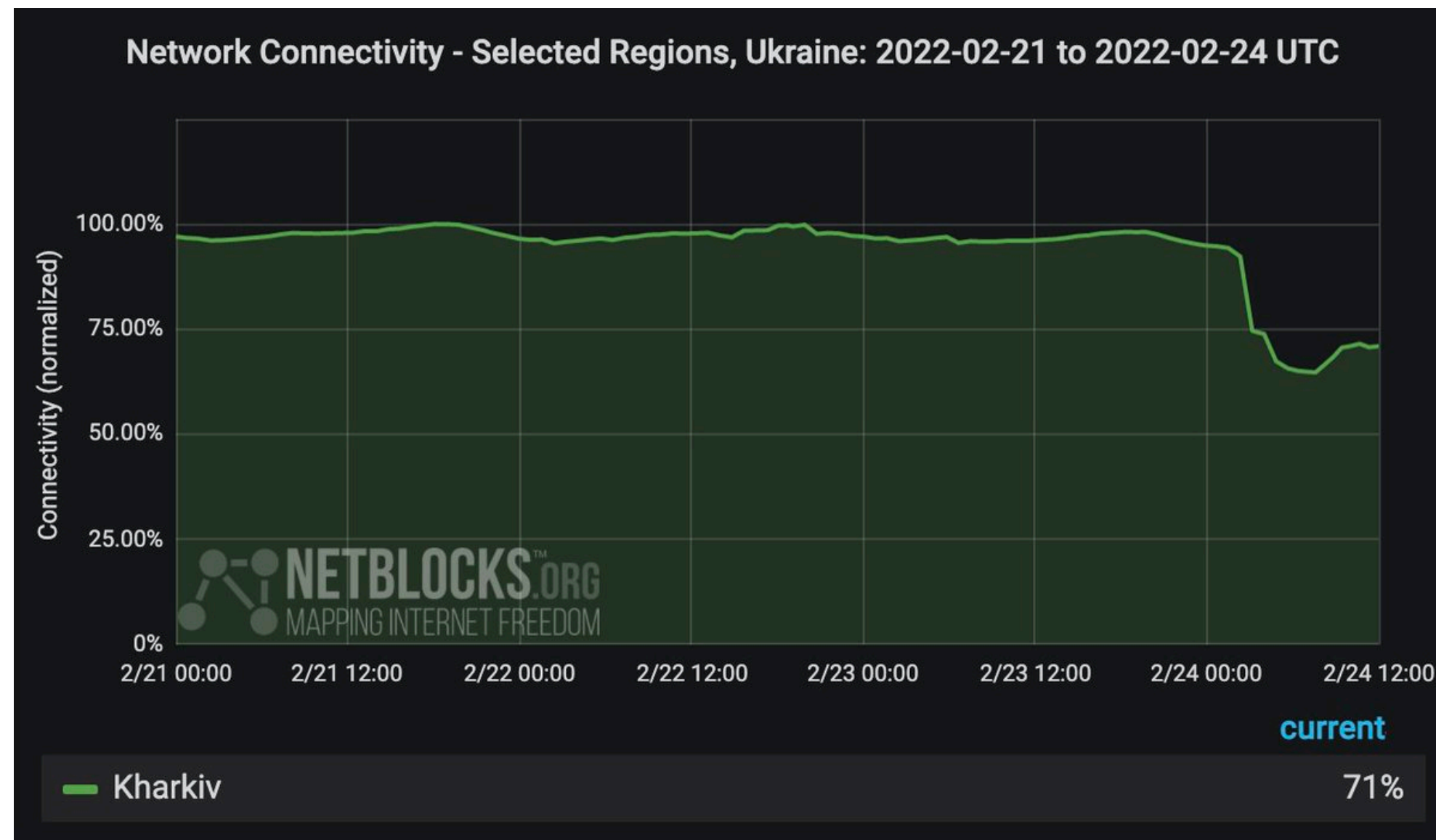Contributor: Emile Aben, RIPE NCC

Beginning

Chronicle of the War's Beginning

- Russia's invasion of Ukraine began on February 24, 2022

- Around 5 AM Kiev time, Russian troops launched missile strikes on targets near Kiev, and long-range artillery strikes on Kharkiv.

- Reports of explosions near Odessa, Dnepr, Mariupol, Kramatorsk, Ivano-Frankivsk, Borispol, Ozernyi, Kulbakin, Chuguev, Kramatorsk and Chernobaivka.

- The Russians fired more than 100 missiles - short- and medium-range ballistic missiles, cruise missiles, and sea-based missiles.

- In parallel, a combined ground offensive was launched from three directions along the entire border from Zhytomyr Region (from Belarus) to Luhansk Region and from Crimea.

Russian Missile Strikes in the First Days

Mass Destruction of Civilian Objects

Internet Disruptions in the First Days of War

Network Connectivity - Selected Regions, Ukraine: 2022-02-21 to 2022-02-24 UTC

Kharkiv — current 71%

Network Connectivity - Selected Regions, Ukraine: 2022-02-16 to 2022-02-25 UTC

POPULATION EXODUS

Kyiv, Kyiv City — min 85%   current 85%

NetBlocks ✔ @netblocks

⚠️ Confirmed: Significant internet disruption registered in #Ukraine-controlled city of #Kharkiv shortly after huge explosions heard; users report loss of fixed-line service on provider Triolan while cellphones continue to work 📉

NetBlocks ✔ @netblocks

ℹ️ Update: Real-time network data show a significant decline in internet connectivity across #Kyiv, Ukraine since early Thursday, attributed to population exodus and the shuttering of businesses and homes as civilians seek shelter or flee.

Degrading of Fixed Line Services

Connected RIPE Atlas probes

Customers started switching to mobile services
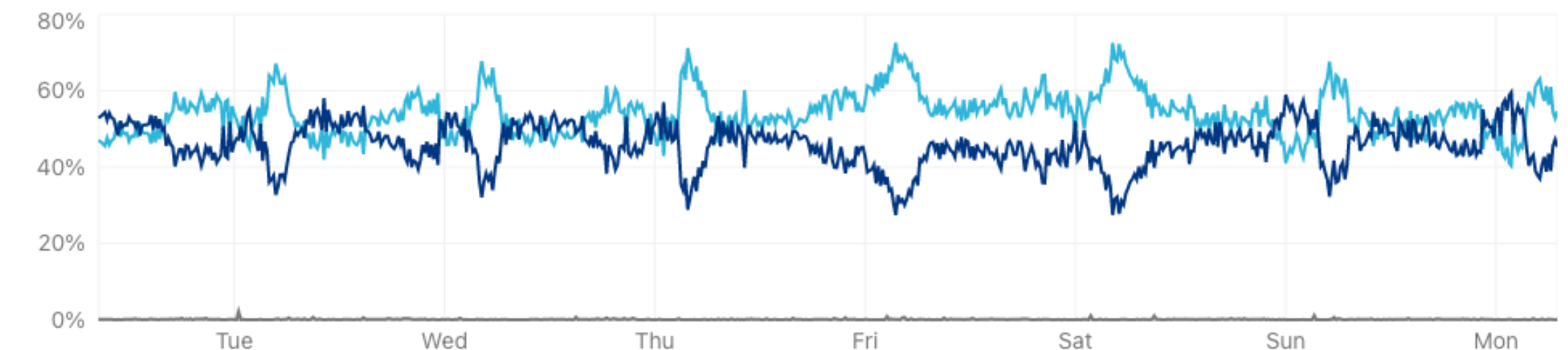
Initial Assumptions

- Rapid destruction of Ukrainian infrastructure

- Panic among the civilian population, including the staff of telecom operators

- Consistent degradation of the Internet up to complete loss of connectivity

Reality

- Failures of individual nodes did not have a fatal effect on connectivity in the country

- Partial losses of connectivity in the Ukrainian segment were quickly restored

- Telecom operators continued to provide services despite the war

The war develops

First Strikes on the Energy Infrastructure

- Data from the first 24 hours (November 24, 2022)

Network Connectivity - Ukraine: 2022-11-14 to 2022-11-25 UTC

Internet Connectivity for Ukraine
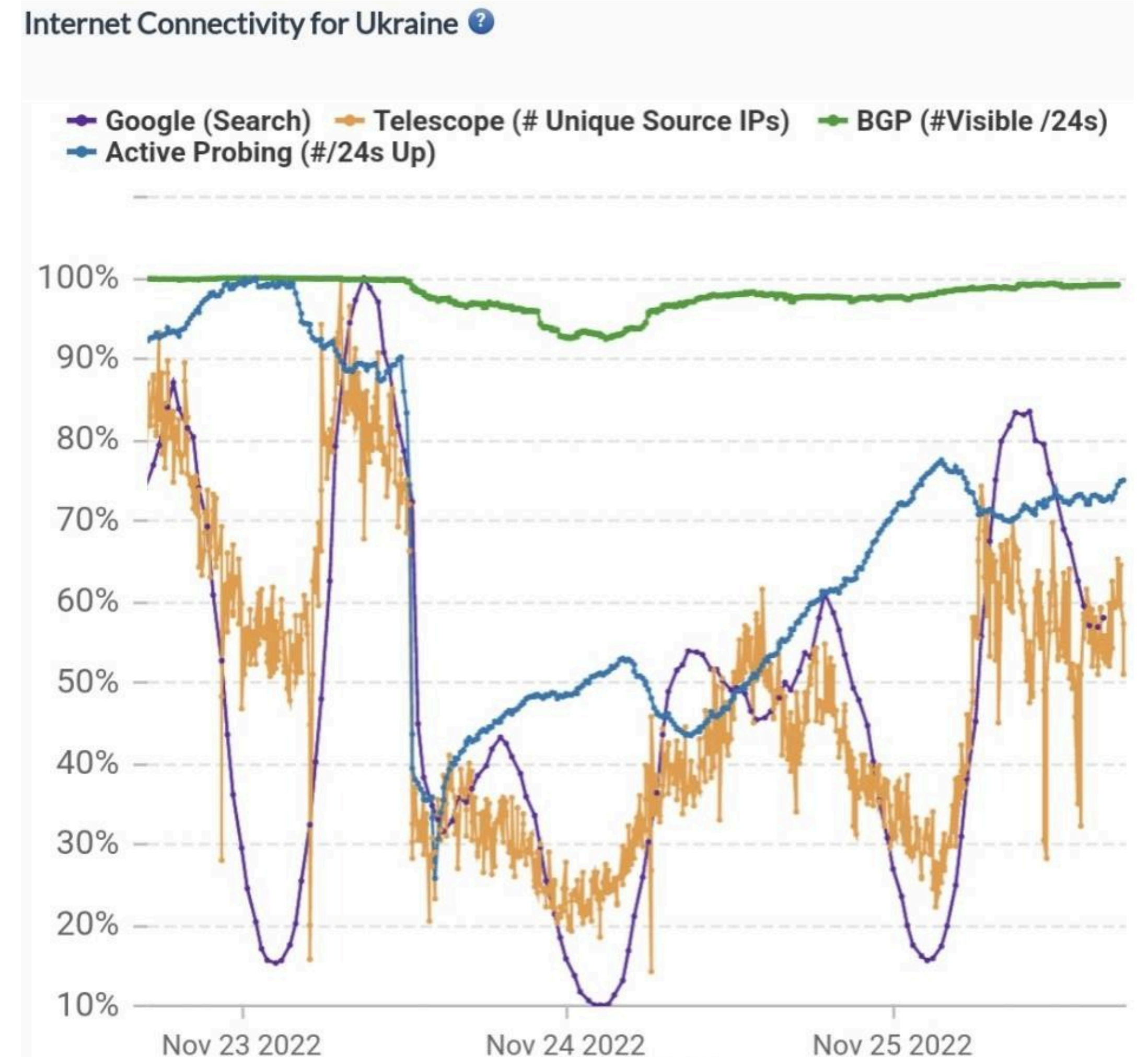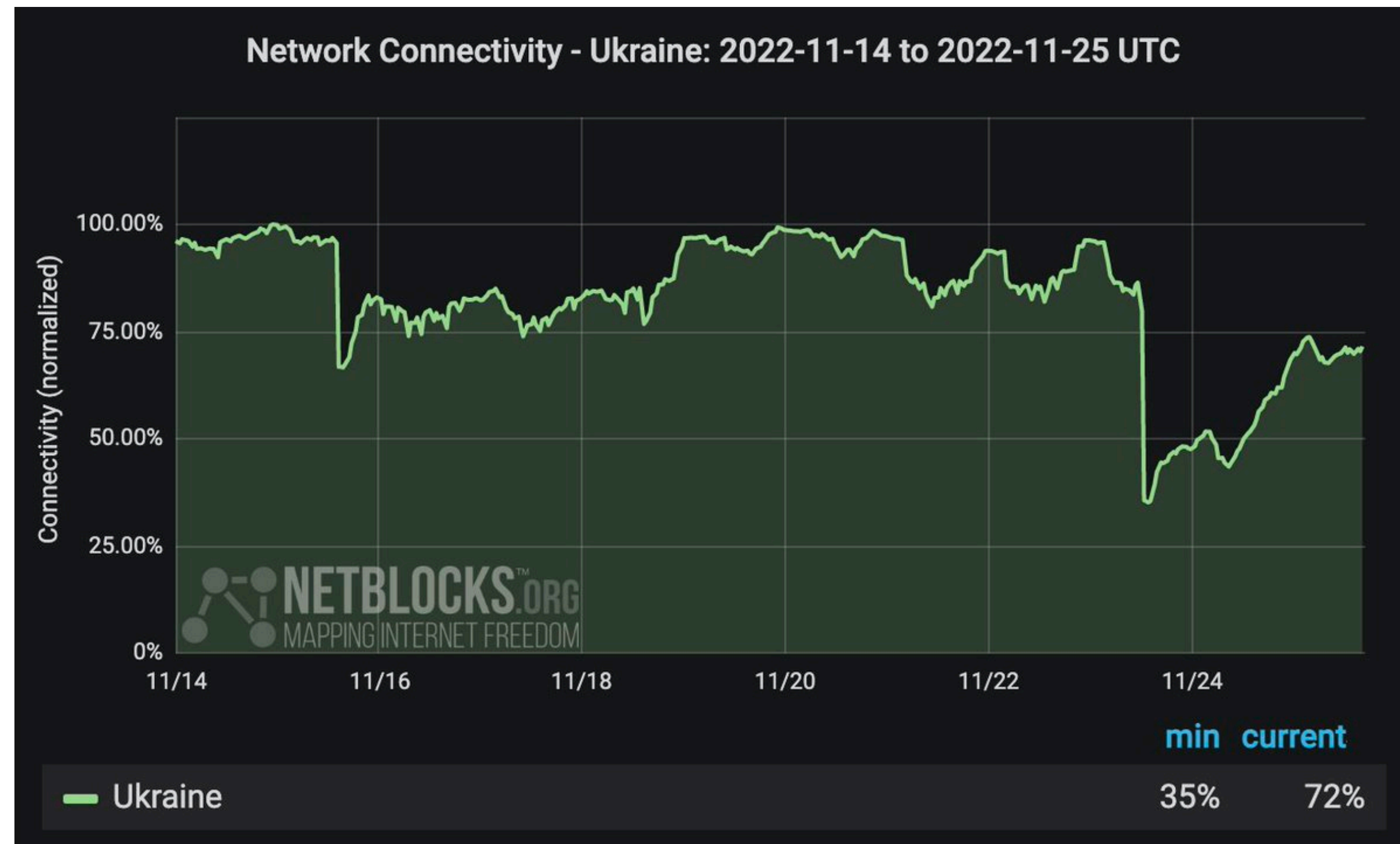
First Power Interruptions

- Power is an evident bottleneck of the physical Internet infrastructure

- Power outages led to disruptions of communications service providers

IODA Signals for AS43554 (CDS-AS)

Alert Bands: ON
Normalized Values: ON

Time (UTC)

● Active Probing (#/24s Up) ● BGP (#Visible /24s) ● Telescope (# Unique Source IPs)
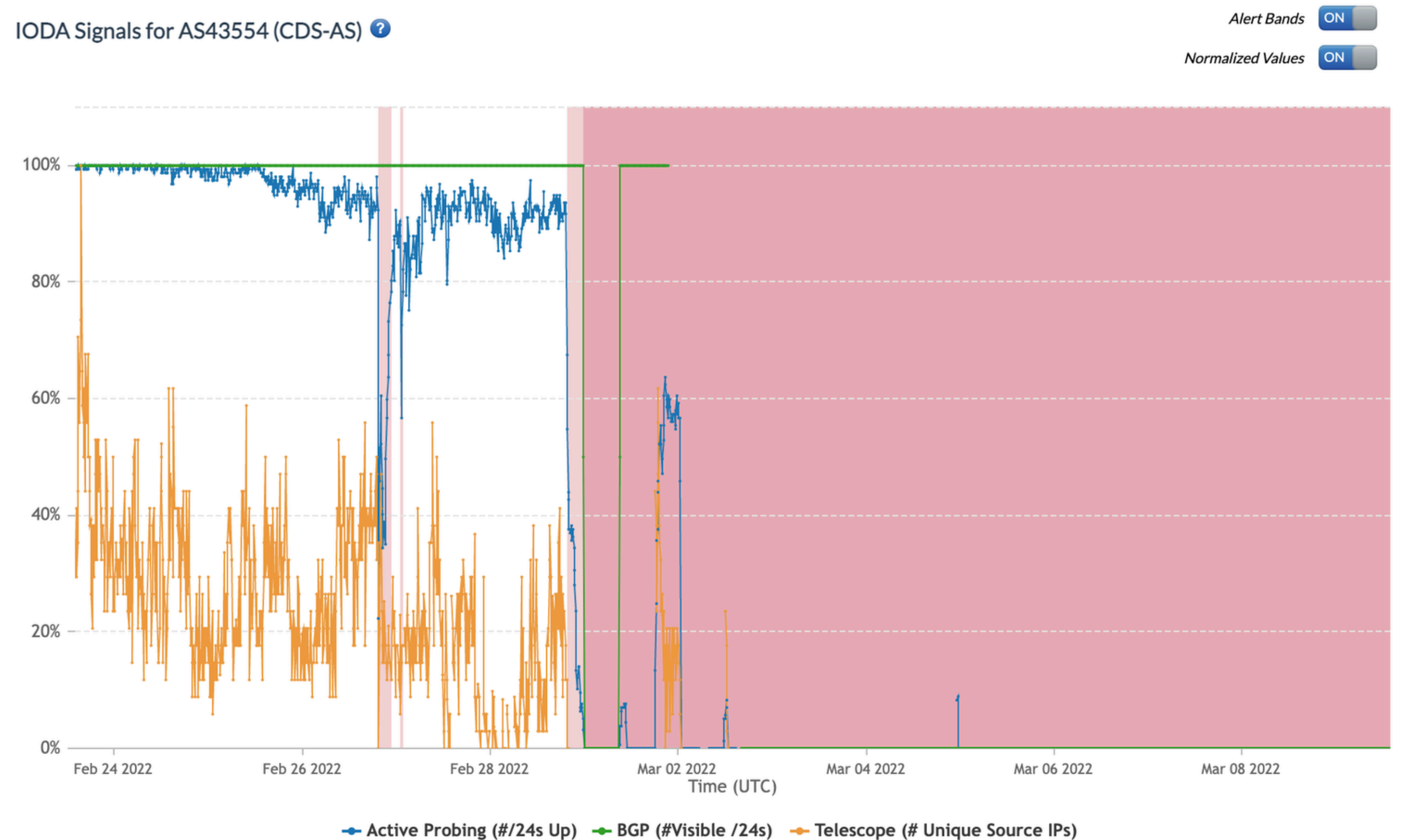
February 23, 2022 2:05pm — March 9, 2022 2:05pm

January: The Scale of Devastation

- Russia destroyed about 10% of Ukrainian energy sector, damaged about half of it (DTEK Group data)

- Ukraine's energy infrastructure: 40 percent of Ukraine's energy infrastructure is out of service (Ukrainian Government)

IODA (Georgia Institute of Technology)

https://ioda.inetintel.cc.gatech.edu/country/UA

Legend:
- Active Probing (#/24s Up)
- BGP (#Visible /24s)
- Telescope (# Unique Source IPs)
- Google (Search)

- Hits to the Internet's physical infrastructure are sensitive, but fixes quickly

- Strikes on energy infrastructure are much more extensive, and have a greater impact

- Nevertheless, the industry recovered relatively quickly in each case

- Ukraine's counterattacks repeatedly improve results

RIPE NCC Data

The graph of the visible prefixes numbers/ASNs also clearly reflects the war course

- Small drop-offs as a result of strikes on cable infrastructure

- Significant dropouts from power system failures

- Unavoidable recovery after

- Counterattacks improve results

- Prolonged fighting in a narrow area along the front line worsens them

https://stat.ripe.net/ui2013/widget/visibility#w.resource=ua
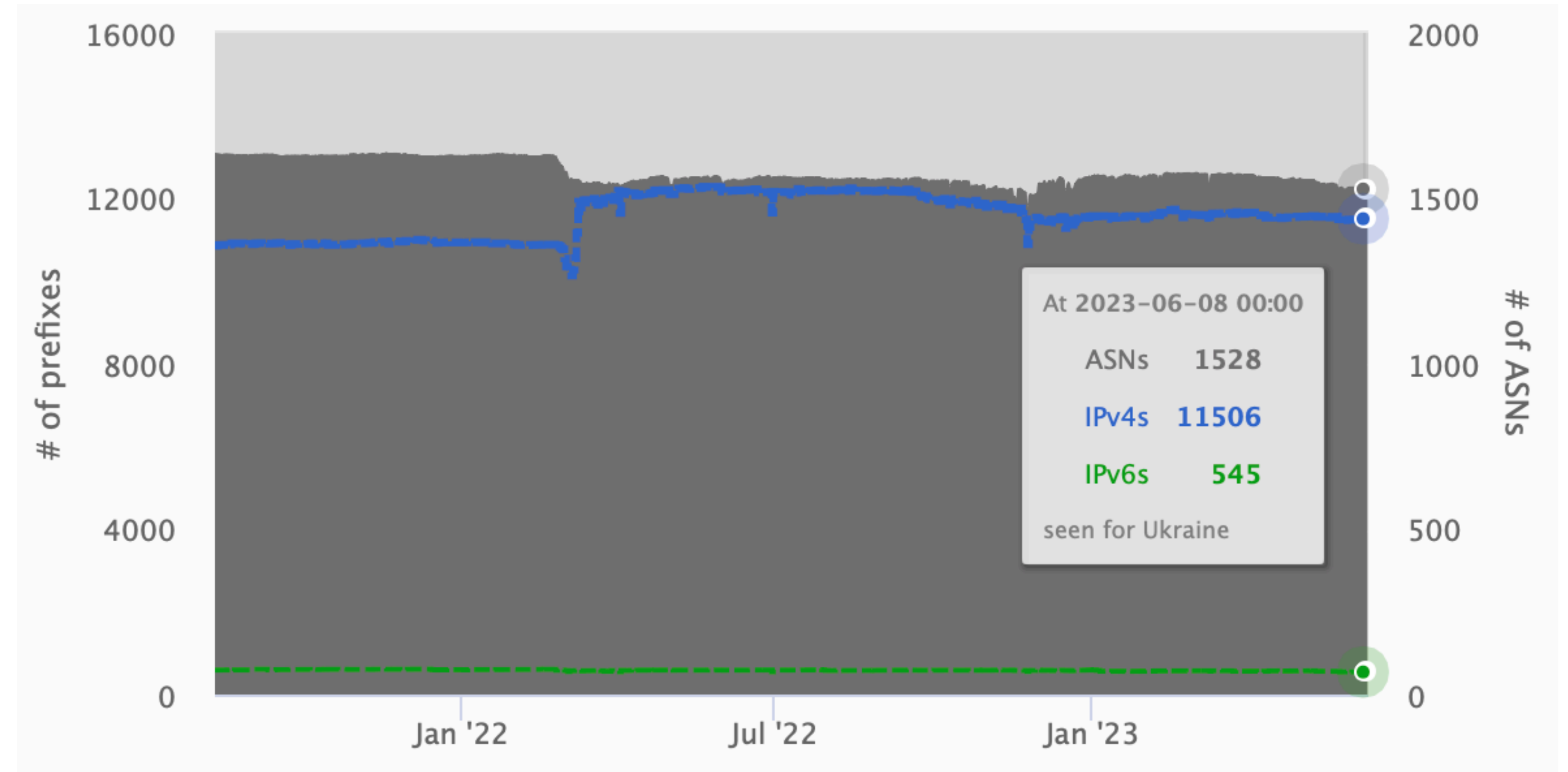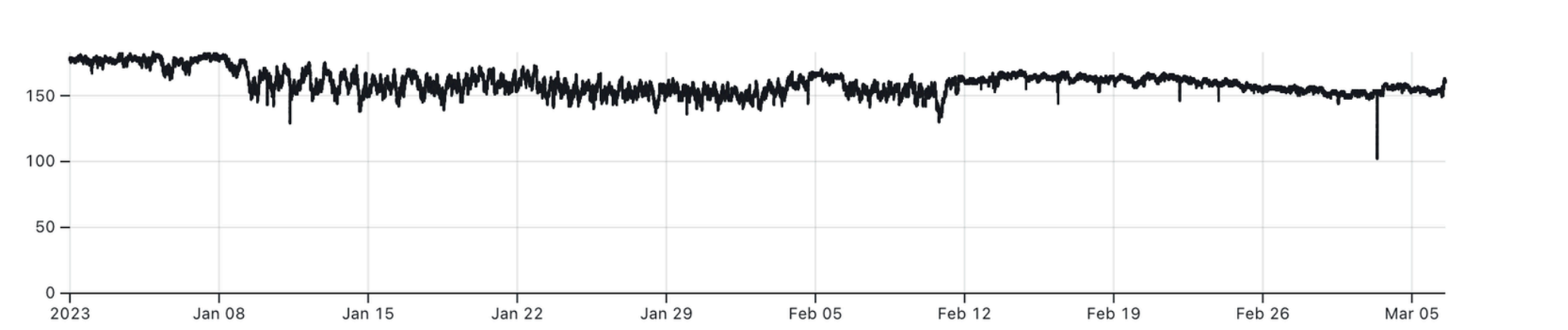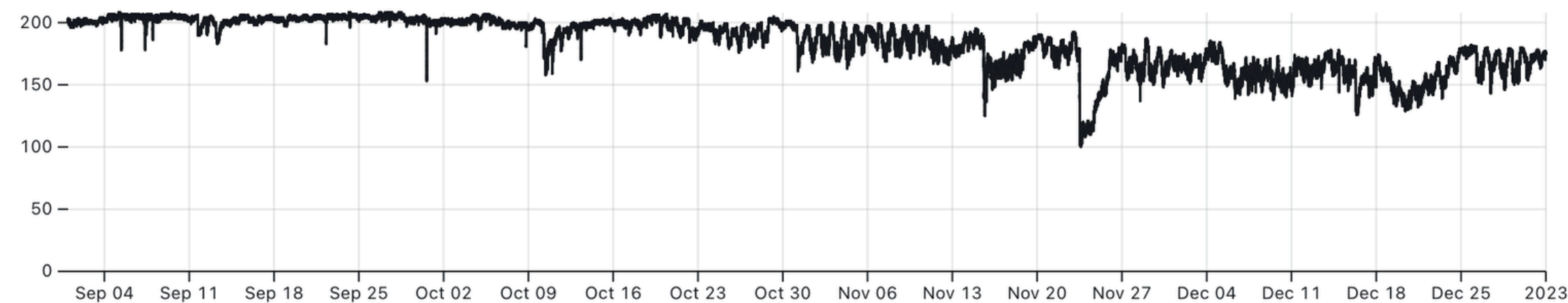
RIPE Atlas probes

- RIPE Atlas is one of the main measurement tools of the RIPE NCC
- These graphs show the change in the total number of RIPE Atlas samples in Ukraine since the beginning of the war
  - Keep in mind that resuming probe operation is often not a priority for operators restoring their operations

Ukrainian Internet Structure by RIS

Ukrainian operators are grey

Foreign ones are pink

Nodes are sized based on their number of direct incoming links
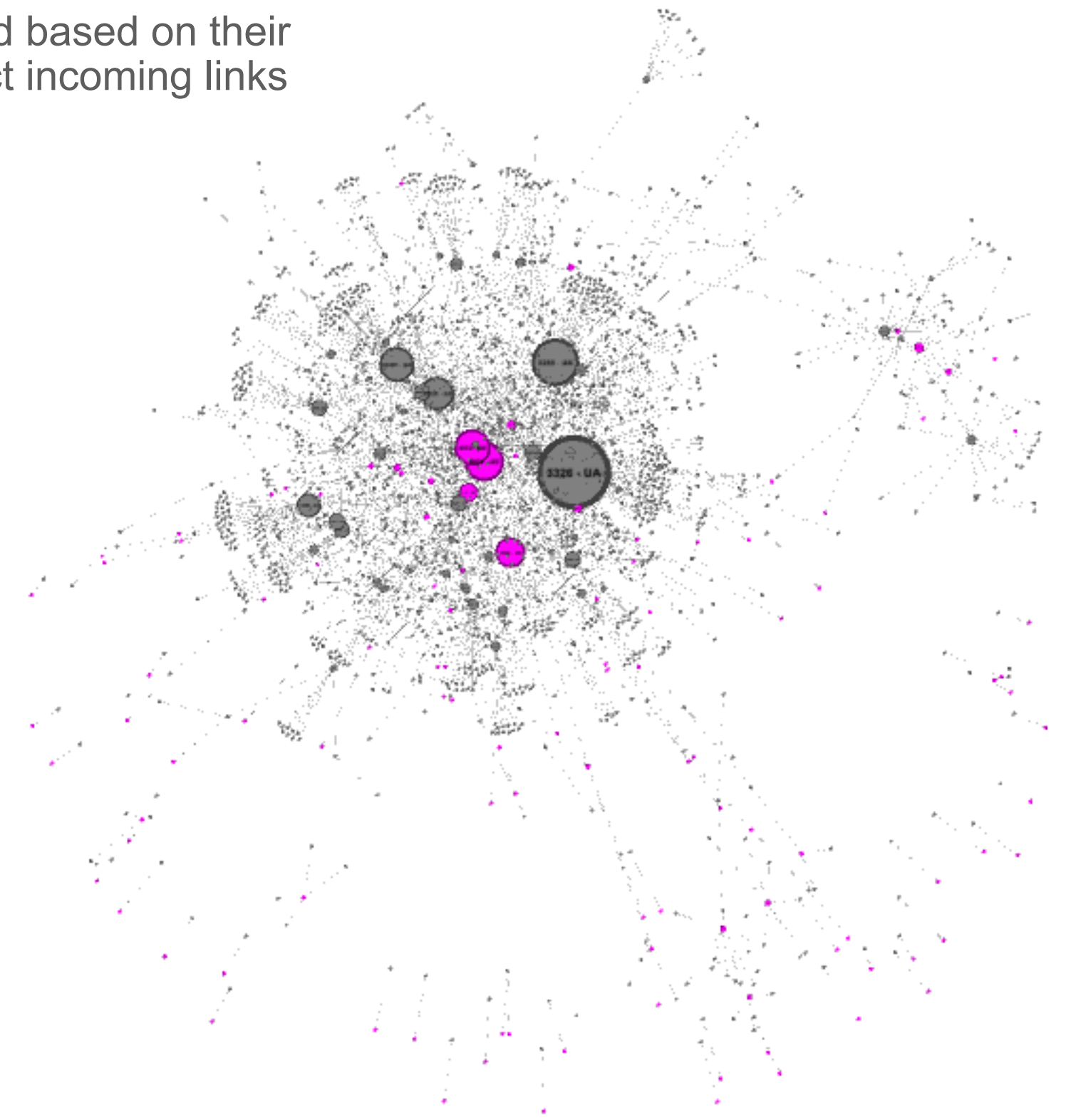
2022-01-01
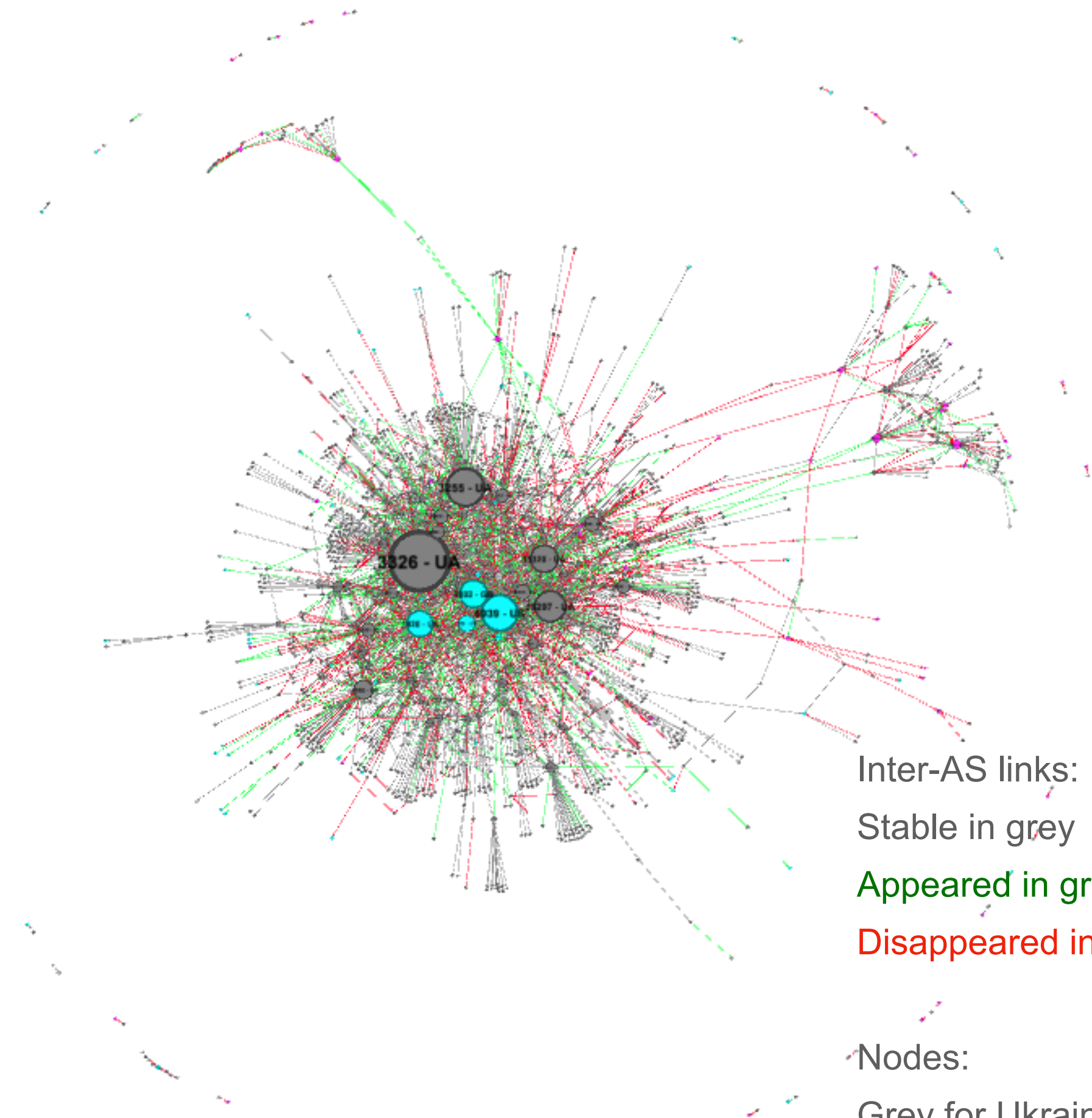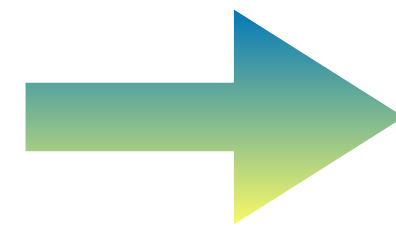
2023-04-01

Inter-AS links:

Stable in grey

Appeared in green

Disappeared in red

Nodes:

Grey for Ukraine-registered networks

Pink for Russia-registered networks

Magenta for all other networks

https://labs.ripe.net/author/emileaben/the-resilience-of-the-internet-in-ukraine-one-year-on/

Ookla's glance

- Mobile services are more sensitive to power outages

- Industry continues evolutionary growth despite war
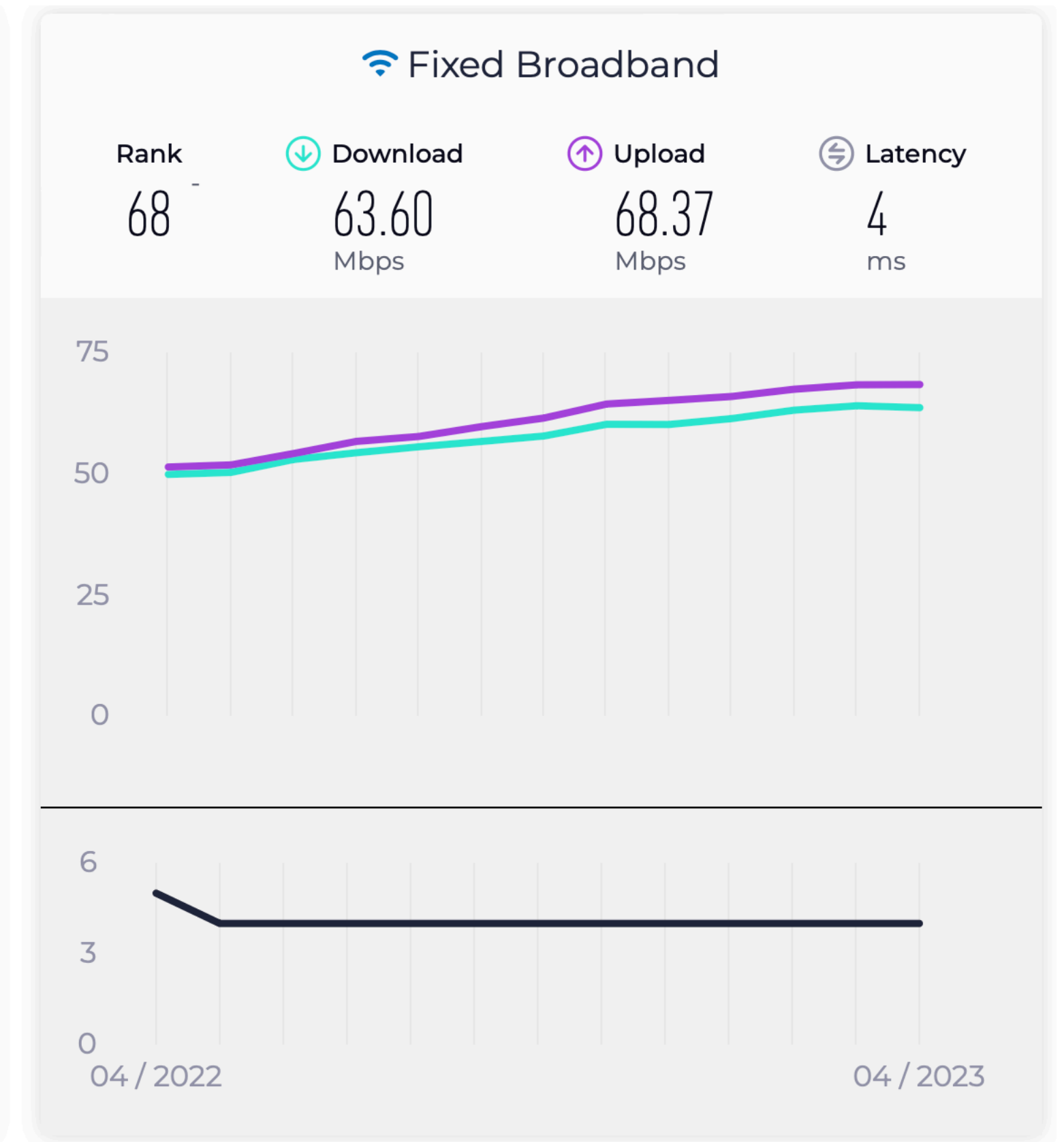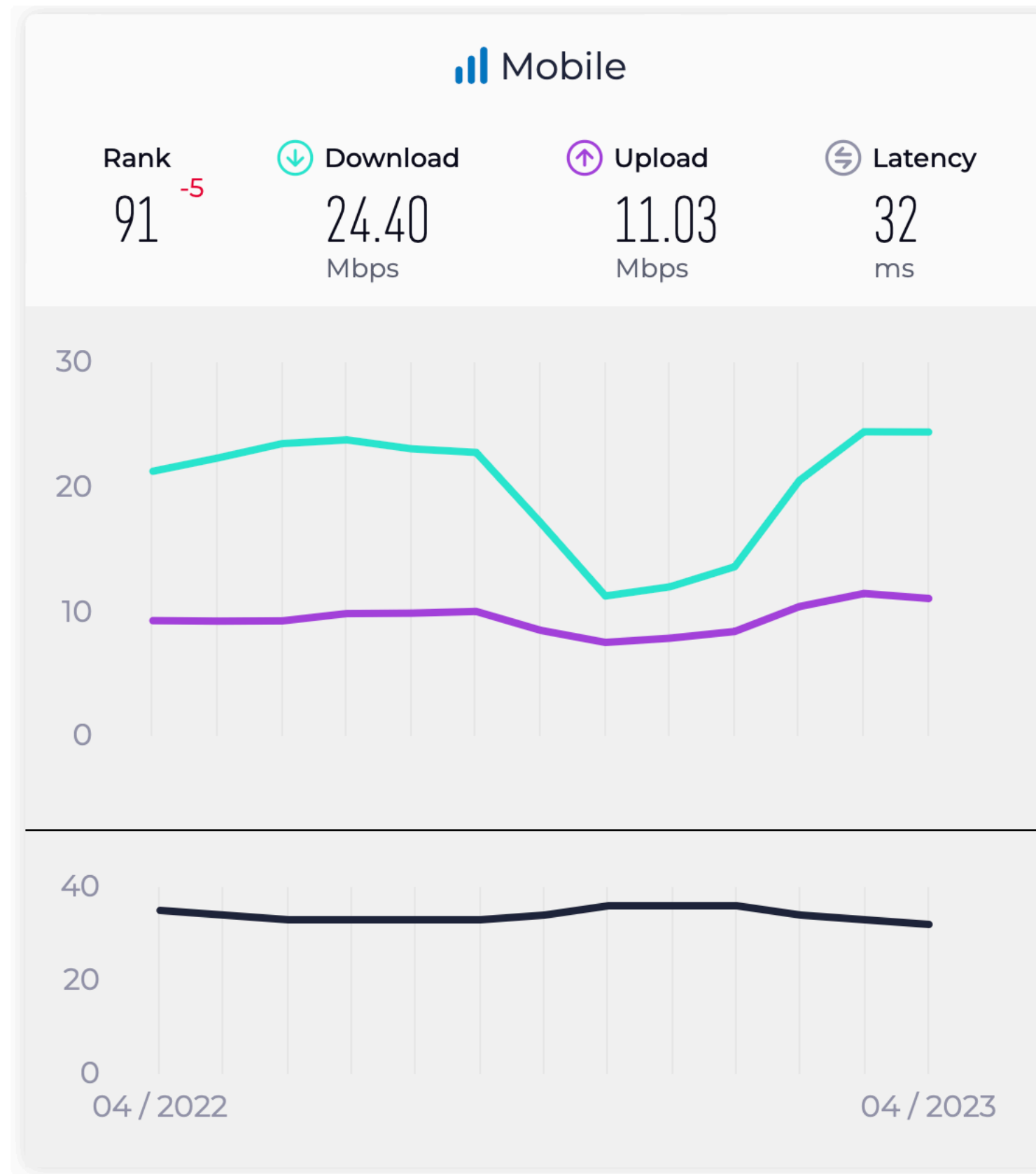
Cloudflare statistics
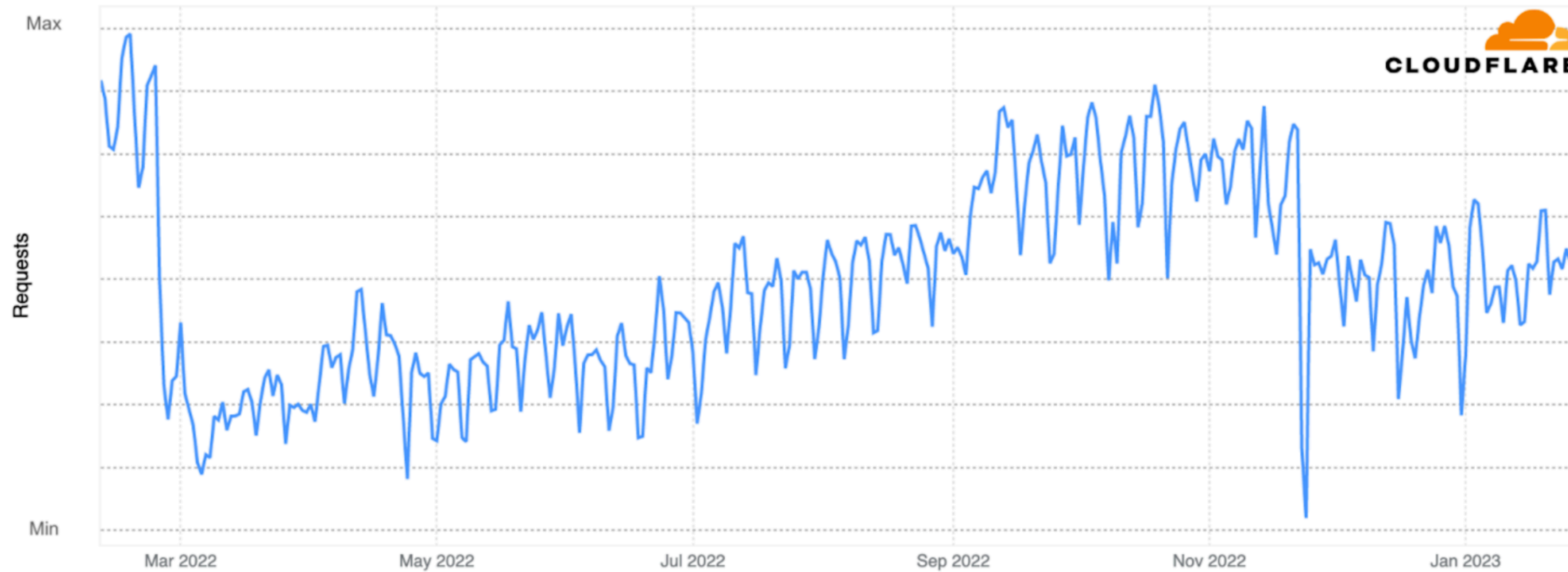
- The number of requests depends not only on the capacity of operators but also on the number of users
- Migration has a strong impact on this indicator
- It is also possible that the sample of resources behind Cloudflare is not fully representative

Google view: negative trends
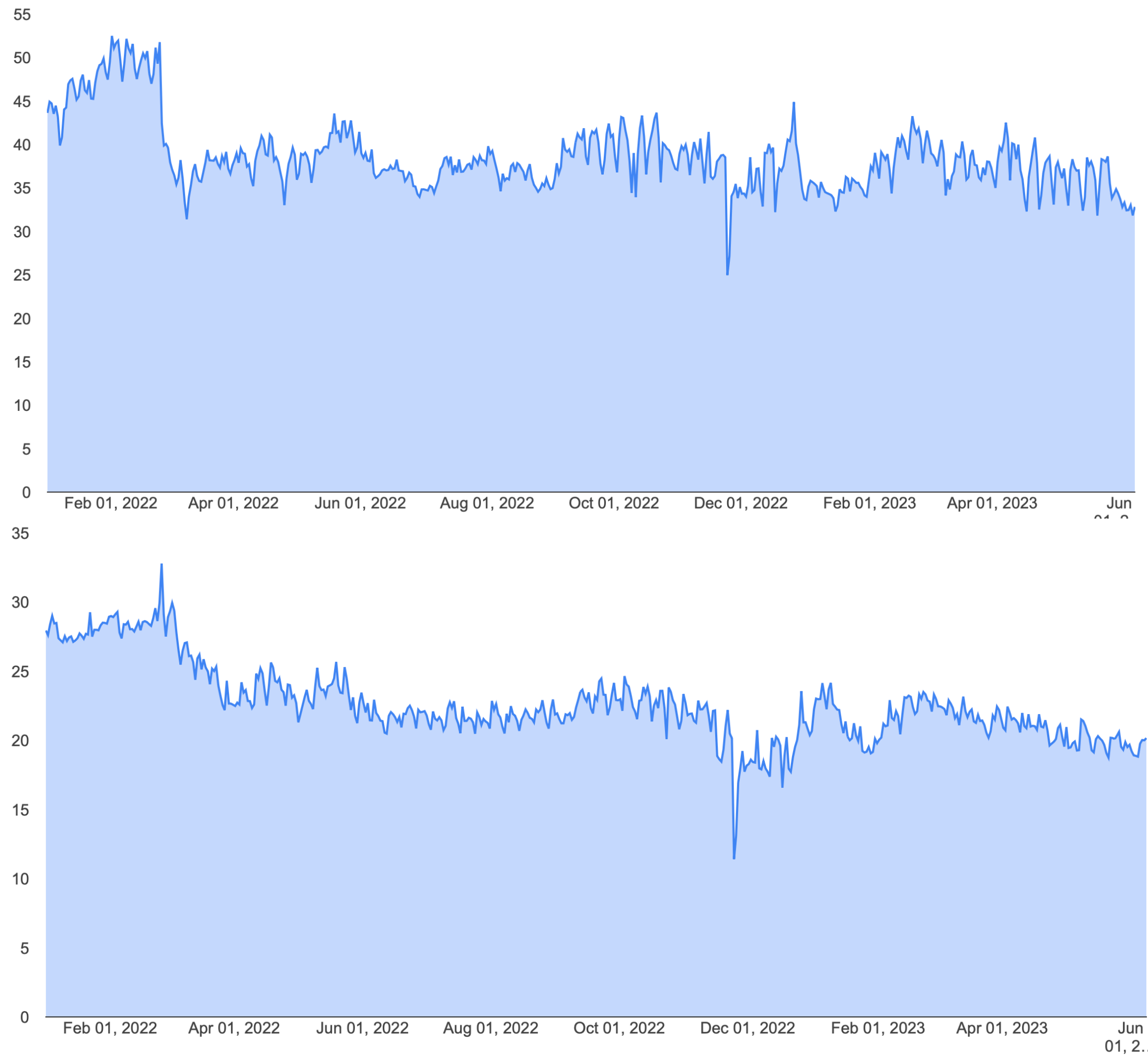
- Users activity: Google Web Search (top) and YouTube (bottom)

- The decline in activity:
  - Complete destruction of civilian infrastructure along the line of contact (Bakhmut as the most famous example)
  - Continued migration from the country

Analysis

Ukrainian Market Overview

- **One of the least concentrated markets worldwide**

  - Herfindahl-Hirschman index (HHI) calculation by Emile Aben (RIPE NCC)

  - APNIC data

  - Correlates with Huawei Cloud HHI calculation (2019)

- **No dominant players in the market**

  - If an individual network goes down, this has a relatively small effect on the whole network

Top 10 least concentrated markets for end-user per network (ASN)

	Country	HHI
1	Brazil	0.018
2	Russia	0.047
3	United States	0.05
4	Ukraine	0.052
5	Lebanon	0.067
6	Singapore	0.069
7	Albania	0.072
8	Guadelope	0.081
9	South Africa	0.083
10	Japan	0.087

Hight Fault tolerance

- Diversification among ISPs leads to increased resiliency

- High degree of diversification of the industry in Ukraine for many years ensured its place in the top ten

2022 Map of IPv4 Top 20 Fault Tolerant Countries

3	NETHERLANDS 3.56%
17	RETURNEE BELGIUM 6.27%
9	RETURNEE IRELAND 4.95%
5	GREAT BRITAIN 3.74%
13	LUXEMBOURG 5.49%
11	FRANCE 5.19%
15	ITALY 5.87%
1	BRAZIL 1.35%
16	ARGENTINA 6.27%

GERMANY 2.49%

| 2 |
8	POLAND 4.89%
6	UKRAINE 4.13%
10	SWITZERLAND 5.03%
19	JAPAN 6.33%
20	RETURNEE HONKONG 6.47%
4	SINGAPORE 3.67%
18	INDONESIA 6.30%

| 14 | RUSSIA 5.50% |

| 7 | CANADA 4.71% |

NEWCOMER SEYCHELLES 5.41% | 12 |

BRAZIL	1
GERMANY	2
NETHERLANDS	3
SINGAPORE	4
GREAT BRITAIN	5
UKRAINE	6
CANADA	7
POLAND	8
IRELAND	9
SWITZERLAND	10
FRANCE	11
SEYCHELLES	12
LUXEMBOURG	13
RUSSIA	14
ITALY	15
ARGENTINA	16
BELGIUM	17
INDONESIA	18
JAPAN	19
HONKONG	20

1.35% ████████████████████ 6.47%

Interconnection in Ukraine

Green circle = end-user networks serving > 1% of the country's population

A large 'gap' in the circle:

more than half of the Ukrainian end-users networks serve less than **1%** of the population

KSNET-AS

UMC-AS

UKRTELNET

VOLIA-AS

LIFECELL-AS

TRIOLAN

UARNET-AS

VOSTOK-UA

FREENET-AS

FREGAT-AS

OT-AS

HURRICANE

UA-IX

DTEL-IX-PUBLIC

GigaNET Kyiv-Global exchange

ETT-AS

Fiord-AS
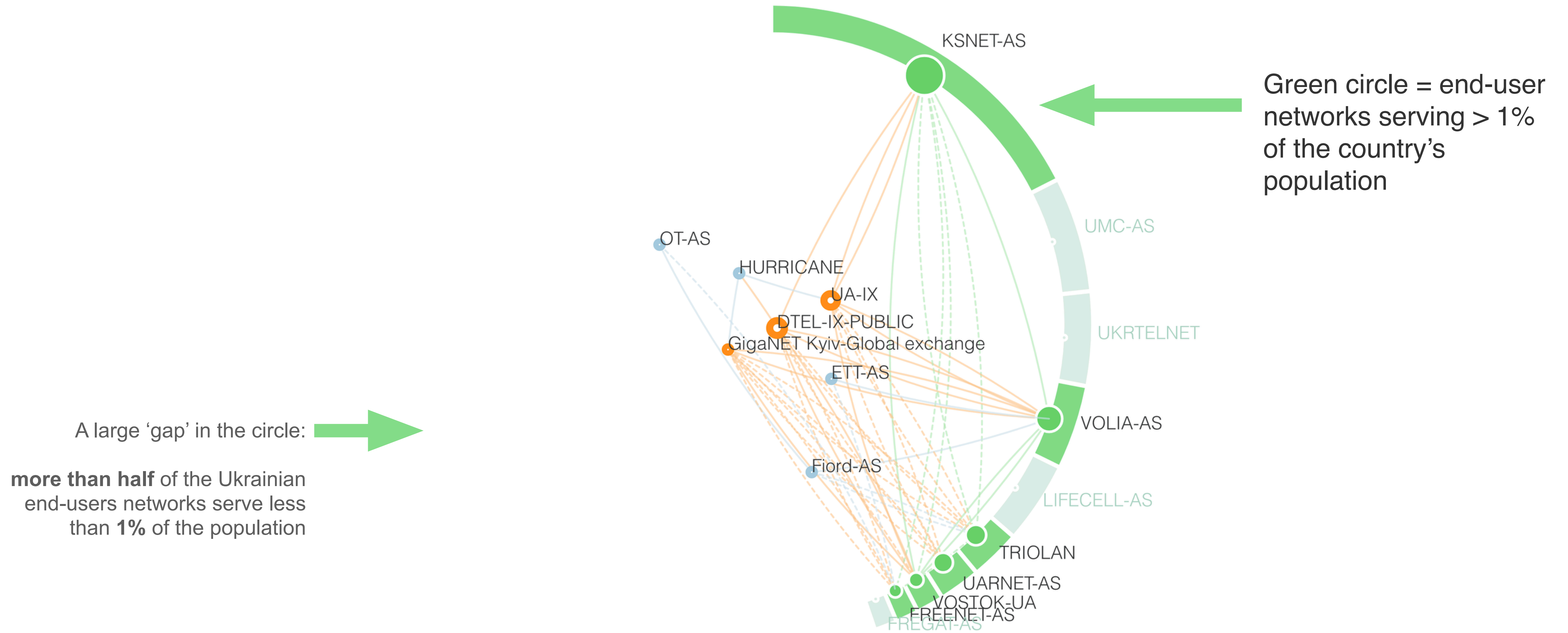
How Ukrainian end-user networks interconnect, as seen from RIPE Atlas

Ukrainian IXPs

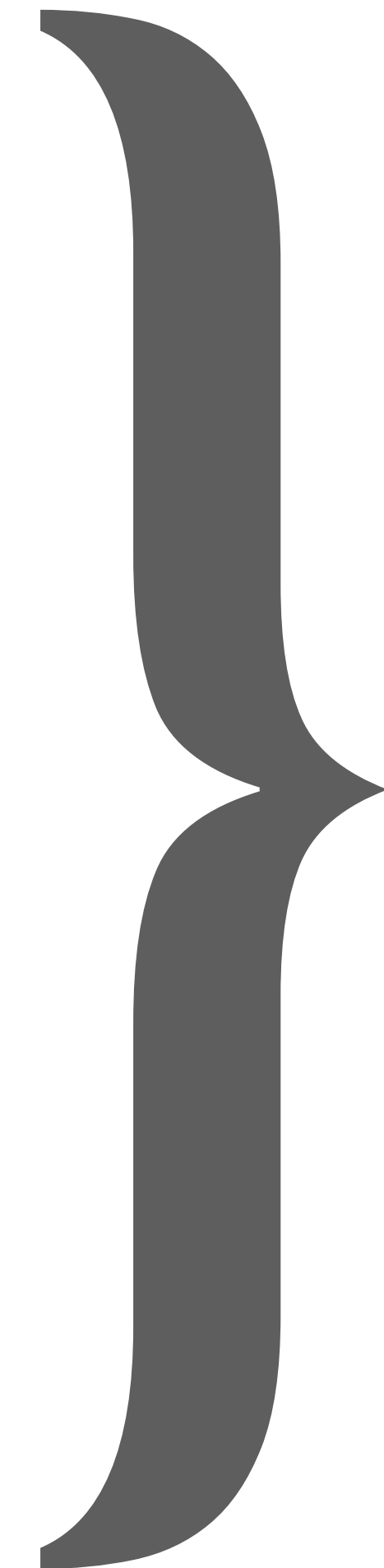| Name	Media Type	Country	City	Network…
GigaNET Kyiv Giganet Internet exchange network	Ethernet	UA	Kyiv	174
DTEL-IX Digital Telecom Internet Exchange	Ethernet	UA	Kiev	166
UA-IX Ukrainian Internet Exchange	Ethernet	UA	Kiev	128
PITER-IX Kiev PITER-IX Kiev	Ethernet	UA	Киев	66
1-IX Internet Exchange 1-IX Internet Exchange	Ethernet	UA	Kyiv	39
GigaNET Odessa GigaNET Odessa local exchange	Ethernet	UA	Kiev	11
CLOUD-IX KIEV CLOUD-IX KIEV	Multiple	UA	Kiev	10
GigaNET Kharkov GigaNET Kharkov local exchange	Ethernet	UA	Kharkov	9
LVIV-IX Lviv Internet Exchange	Ethernet	UA	Lviv	9
IF-IX IVANO-FRANKIVSK INTERNET EXCHANGE	Ethernet	UA	Ivano-Frankivsk	8
CLOUD-IX KHA	Multiple	UA	Kharkov	6
Crimea-IX Crimea-IX	Ethernet	UA	Simferopol	6
MESH-IX Mesh Internet Exchange	Ethernet	UA	Mariupol	5
RUDAKI-IX RUDAKI INTERNET EXCHANGE	Ethernet	UA	Kyiv	5
Kherson Traffic Exchange Kherson Traffic Exchange	Ethernet	UA	Kherson	4
kremen-IX	Ethernet	UA	Kremenchuk	3
DN-IX Donetsk Internet eXchange	Ethernet	UA	Donetsk	2
KM-IX Khmelnitskiy Internet Exchange Point	Ethernet	UA	Khmelnitskiy	2
SerinIX IX SerinIX Internet Exchange	Ethernet	UA	Kiev	1

19 IXPs

(1 in Crimea)

Ukrainian IXPs

- kremen-IX
- UA-IX
- LVIV-IX-Main
- KM-IX-Main
- IF-IX-Ivano-frankivsk local exchange
- GigaNET Odessa-Odessa local exchange
- GigaNET Kyiv-Global exchange
- GigaNET Kharkov-Kharkov local exchange
- DTEL-IX-PUBLIC
- DN-IX
- Crimea-IX
- CLOUD-IX KIEV
- 1-IX Internet Exchange

Destination (North to South)

13 of them are in the tracks between the RIPE Atlas probes in the country

- Each cell here: A path between RIPE Atlas probes in Ukraine

- The majority of these paths are mediated by IXPs (the total of coloured cells)

- Many different IXPs are used, indicating that there is not a single dominant IXP

Our interpretation

- In the Ukrainian segment of the Internet since the beginning of the war, more connections have been lost than gained

+ A significant number of new connections is noticeable

- There is a gradual decrease in the number of connected RIPE Atlas probes.

+ "Waviness" in the graph of connected probes has leveled off recently, indicating a more stable Internet in recent months.

+ The number of working IXPs has remained stable since the beginning of the war

Diversity

- After major strikes on energy infrastructure, it took one-two week almost to regain the quality of service for small and medium-sized ISPs

    - Sadly, major missile strikes occurred every few days, so a full recovery in between was impossible

- However, there were still significant disruptions in the service of major operators all winter long

- Due to the relatively small total share of large operators, the *problem* did not turn into a *catastrophe*

Human Factor

Free Internet Access in Bomb Shelters

Despite the drop in revenues, operators have taken on additional social functions

Operators During the War

- Free internet access in bomb shelters

- Free "national roaming" amongst mobile operators

- Sharing inventory of spare parts

- Repairing emergencies on one operator's network by another operator's teams

- The network restoration right in the middle of the warfare

- The daily heroism of employees

People: ISPs
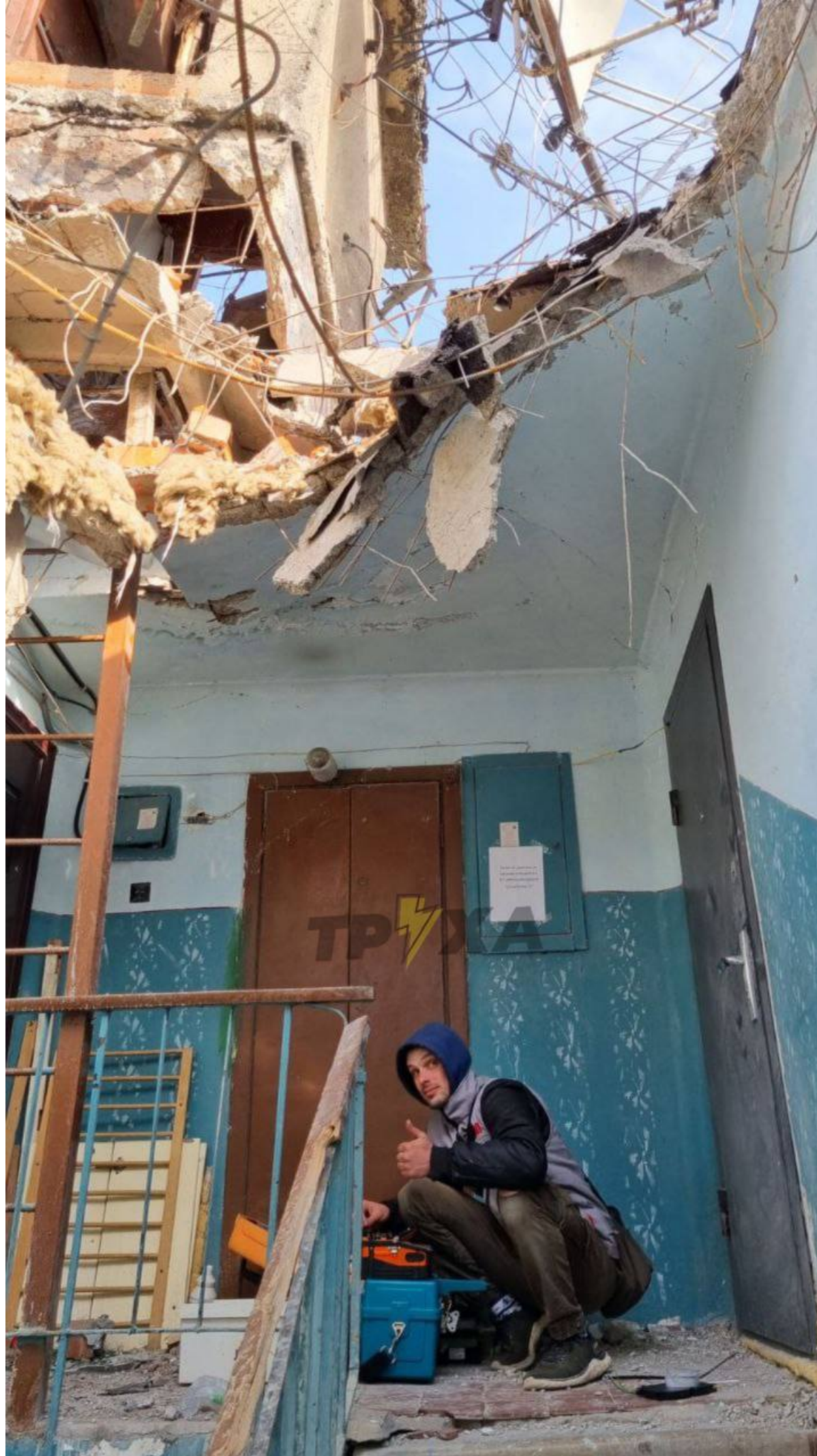
People: ISPs

People: power companies

Labor feat

- Weekend work

- Work with a break only for sleep

- Workers often slept on the jobsite

Help from Abroad

Starlink

Starlink proved to be indispensable in several special cases

- Military communications
  - In particular, communication on the combat line
- Communication for government agencies

Starlink

- Communication in the recently de-occupied territories

Keep Ukraine Connected

- An initiative of the Global NOG Alliance

- A platform to collect equipment for the Ukrainian ISPs affected by the war

- The amount of aid already provided exceeds 2 million euros

https://nogalliance.org/our-task-forces/keep-ukraine-connected/

Keep Ukraine Connected

Sander Steffann

Rene Fichtmueller

Jan Žorž

Corinne Pritchard

Nathalie Trenaman

Ester Paál

Daniel Houben

Marcin Kuczera

Erik Bais

Summing Up

Conclusions

- Obviously, a war does have a huge impact on connectivity

- Diversifying infrastructure dramatically increases its reliability

- There are still bottlenecks to Internet infrastructure - in particular, power provision

- Quick focused help is extremely helpful

  - The Ukrainian army was helped by Starlink

  - Internet service providers were helped by the community

  - Energy companies were helped by many governments

- The key factor remains the people who keep the systems running

Not covered here

- A cyberwar

  - Application-layer cyber attacks in Ukraine rose 1,300% in early March 2022 compared to pre-war levels, according to Cloudflare

  - Major incidents like hacking into a satellite Internet provider's network

- Re-routing incidents

- Mutual theft of information

  - All personal data of Russians have already been stolen more than three times — Ukrainian CyberAlliance

- Takeovers of Ukrainian companies

Questions

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