Impact of road congestion on mobile networks

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I. Context

With the increasing number of vehicles equipped with connected services, whether it's security services (eCall, Emergency Assist by Volkswagen, etc.) or infotainment systems (Android Auto, Apple CarPlay, proprietary systems), the automotive sector has become a consumer of bandwidth on cellular networks [1]. Furthermore, the habits of road users have evolved, and they are leaving traditional radio behind in favor of audio streaming services for entertainment [2], which is also a source of traffic that must be managed by cellular networks.

Because of this use of cellular networks to operate vehicles as well as the road infrastructure, we study the impact that road congestion could have on mobile networks. In effect, if vehicles are increasingly connected, we can assume that a large concentration of vehicles in the same area, such as a traffic jam, would lead to an increase in network load and have a negative impact on the performance of the mobile network in that area. This in turn could impact the road services at a time where they are strongly needed. Here, we aim to answer that question.

II. Methodology

To understand the performance of the mobile networks, a major mobile operator provided performance indicators for their antennas in a European country, with a granularity of one hour.

We collected road events published by the highway company during the period of July and August 2024. We limited our collection of road events to major road networks, including highways, as events on local roads were deemed unlikely to have a substantial impact on mobile networks due to the relatively low number of users they would affect. The highway company provides us with information on the location and classification of road events. We chose to filter the events to only include those related to congestion, while excluding events associated with roadwork and accidents. This is because roadwork events often span a prolonged period, making it challenging to establish a suitable reference period for comparing network performance. Finally, accidents almost always generate a congestion event. However, the severity of an accident is not directly related to the severity of the congestion it causes.

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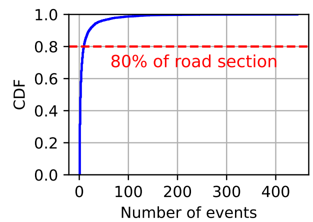

Fig. 1. Cumulative distribution of events per road section

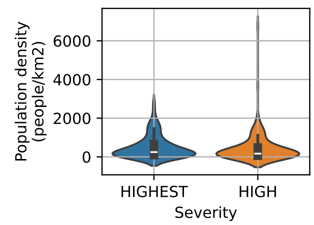

Fig. 2. distribution of events per popultation density

Furthermore, an analysis of the distribution of events across different road sections, illustrated in Figure 1, led us to exclude the top 20% of sections that experience the most events. The rationale behind this decision is that the high frequency of events on these sections renders them non-exceptional, as their occurrence is relatively commonplace.

In addition, because of the hourly resolution of the antenna-level performance data, events lasting less than 30 minutes have been excluded from the analysis. This decision was made in light of the potential for misinterpretation of the impact of these events, which may not be perceptible due to their brief duration.

Following the filtering process, our dataset consisted of 1,838 events. An analysis of the severity distribution of these events, presented in Table I reveals that the majority of events are characterized by moderate severity. Due to the limited number of events with the lowest severity, we decided to exclude them from further consideration in the study. We focus on event marked from low to highest severity level.

To summarize, in the following study, we will only consider road events related to congestion with a severity level superior to the lowest, lasting over 30 minutes, and occurring on roads with a relatively low frequency of incidents. This selection should be favorable to determine if road congestion may lead to increased load on the mobile network.

Upon visualizing the different road sections with the number of events concerning these sections, we noticed that the majority of events are concentrated around the capital and at major intersections. This raises the question of how the location and environment of events can influence mobile network performance. One of our assumptions is that population density is an important factor, as we can expect mobile networks to be more resilient in more populated environments. To be able to

TABLE I
TRAFFIC EVENTS COUNT

Severity	Number of events
HIGHEST	83
HIGH	146
MEDIUM	932
LOW	654
LOWEST	23
Total	1838

verify this in the rest of our study, we collected data on the population density around the event area.

Additionally, it is notable that the events seem to be fairly uniformly distributed throughout the highway network, considering the relatively brief data collection period. This suggests that the data collection was able to capture a representative sample of events across the network, despite the limited time frame.

Figure 2, illustrates the distribution of events in relation to the surrounding population density. It is evident that most events occur in areas with relatively low population densities. This is likely because highways are often constructed in areas with low population densities, as they can be a source of disturbance and require a significant amount of space.

To associate a set of antennas with each event and analyze network performance during the event, we utilized data from a 4G signal strength measurement campaign conducted on roads by the national telecommunications regulator. This data allowed us to identify the three antennas from the Mobile provider with the strongest signals for each point on a road section. These antennas are most likely to be used by drivers. We then aggregate the set of closest antennas for each point of a road section and look at the load on the set of resulting antennas to determine if they are impacted an event of the road segment.

In order to assess the impact of events on antenna performance, a reference point was established through a comparison of the performance of the antennas during the event with their performance at the same hour during the preceding and following weeks.

III. RESULTS

Once the data had been retrieved, we began our analysis by trying to identify which events had an impact on the mobile network.

Referring to Figure 3, which illustrates the distribution of antenna activity time in relation to event severity, we notice that low and medium severity events do not lead to an increase in antenna activity. In contrast, high and highest severity events are associated with increased antenna usage. As a result, we have chosen to exclude low and medium severity events from our analysis, as they do not seem to have a substantial impact on the mobile network's performance.

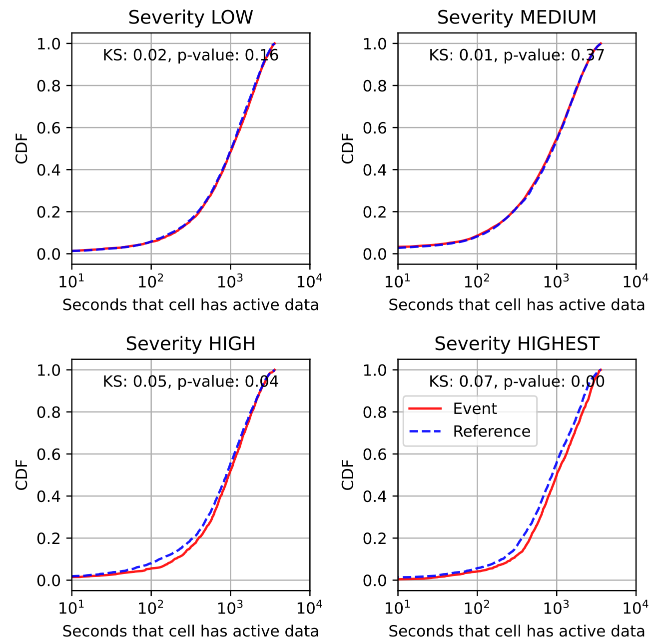

Fig. 3. Cumulative distribution of seconds that cell has active data during a congestion event compared to reference

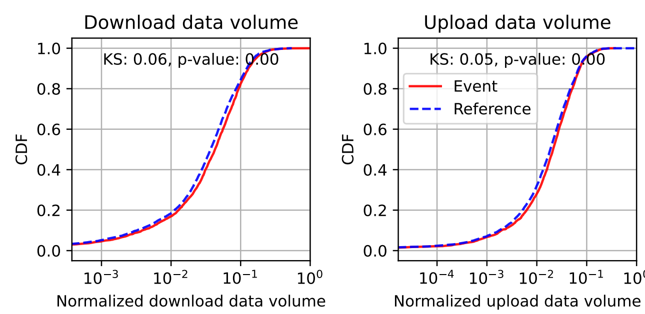

Fig. 4. Data volume exchanged by antennas during a congestion event compared to the reference

The next step is to examine the performance factors of the antennas, including the volume of data exchanged and its throughput.

Figure 4 shows the distribution of the amount of data exchanged by the antennas during the event, both in download and upload, compared to the reference period. We can see that the amount of data exchanged during the event is higher than during the reference period.

Looking at Figure 5, which shows the distribution of antenna throughput during an event compared to the reference period, the overall difference in throughput is not pronounced. However, a closer look at the download throughput of the antennas reveals a slight decrease during events, suggesting a potential impact on performance.

The observed increase in data volume and decrease in throughput may indicate a higher load on the network.

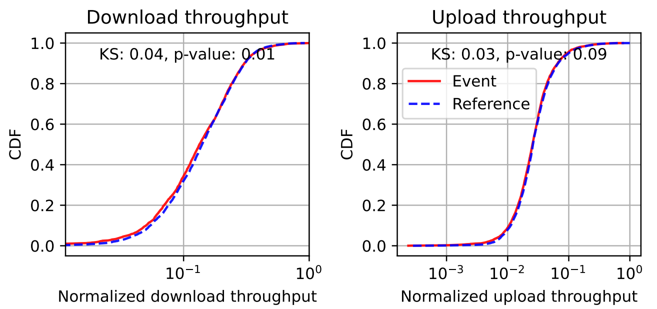

Fig. 5. Antenna throughput during an congestion event compared to the reference period

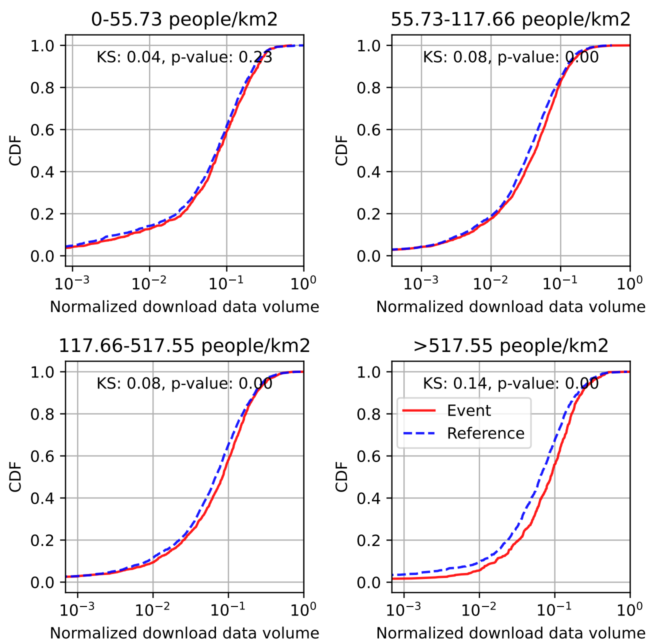

Fig. 6. Data volume for events in areas with different population densities

Nevertheless, the differences are not statistically significant enough to draw a definitive conclusion. Upon performing a Kolmogorov-Smirnov test to determine if the distribution of data during the event is significantly different from the distribution during the reference period. We can see that the obtained score is low (0.06 and 0.05 for Figure 4, 0.04 and 0.03 for Figure 5), which means that the two distributions (during the event and without the event) are quite close.

Although the differences between the two distributions were minor, we chose to pursue the investigation to determine if the surrounding population density affected mobile network performance during events.

We continued to monitor data volume and antenna throughput, but this time we separated events by population density. Figure 6 reveals a higher volume of data exchanged in dense areas during events.

In terms of antenna throughput, Figure 7 shows that events

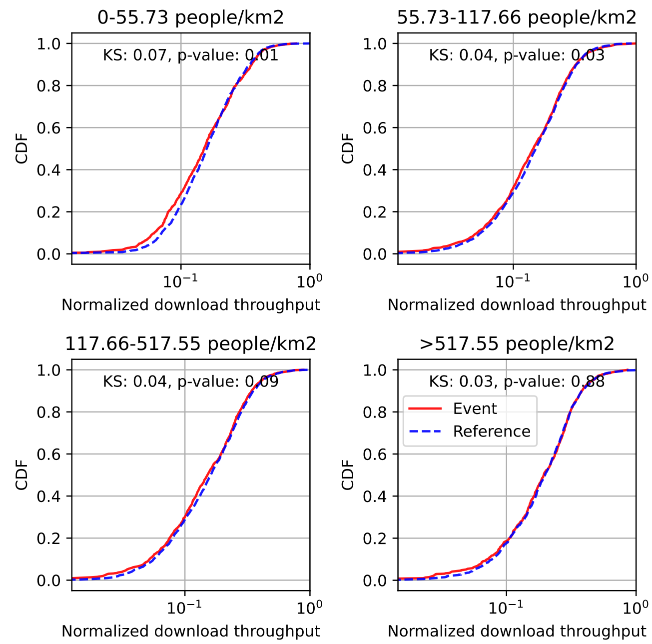

Fig. 7. Throughput for events in areas with different population densities

have little impact on throughput in high-density areas. However, in less densely populated areas, road events appear to decrease throughput. This discrepancy may be attributed to the fact that mobile networks in densely populated areas are designed to accommodate larger loads, making the additional load from a road event less noticeable. In contrast, networks in less densely populated areas are designed for smaller loads, allowing the impact of a road event to be more apparent

Nevertheless, our conclusions are limited by the similarity between the two distributions, as indicated by the Kolmogorov-Smirnov test. Additionally, the reduced number of events after separating events by population density may introduce bias into the statistical analysis, making it challenging to draw definitive conclusions.

IV. Conclusions

With the current data it is not possible to conclude formally that road events have an impact on the performance of mobile networks, even if some trends seem to be present. The study needs to be continued further to see if, with the renewal of the automotive fleet and the increase in connected services that are more resource-intensive, these trends are confirmed.

Acknowledgments

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References

[1] C. E. Andrade, S. D. Byers, V. Gopalakrishnan, E. Halepovic, D. J. Poole, L. K. Tran, and C. T. Volinsky, "Connected cars in cellular network: a measurement study," in *Proceedings of the 2017 Internet Measurement Conference*, ser. IMC '17. New York, NY, USA: Association for Computing Machinery, 2017, p. 235–241. [Online]. Available: https://doi.org/10.1145/3131365.3131403

[2] Edison-Research. The infinite dial 2024. [Online]. Available: https://www.edisonresearch.com/wp-content/uploads/2024/06/Infinite-Dial-2024-Presentation.pdf