Analyzing Throughput and Stability in Cellular Networks

Ermias Walelgne [1] Jukka Manner [1] Vaibhav Bajpai [2] Jörg Ott [2]

April 25, 2018 — NOMS'18, Taipei

[1] (ermias.walelgne | jukka.manner)@aalto.fi, Aalto University, Finland

[2] (bajpaiv | ott)@in.tum.de, Technical University of Munich, Germany

April 25, 2018 — NOMS'18, Taipei

Introduction

Introduction — Motivation

Introduction — Motivation

- Mobile-broadband subscriptions have grown more than 20% annually in the last five years (ITU 2017) [1]

Introduction — Motivation

- Mobile-broadband subscriptions have grown more than 20% annually in the last five years (ITU 2017) [1]
- Smartphones (in 2017) have 70% share of the total market of all device types (IDC) [2].

Introduction — Motivation

- Mobile-broadband subscriptions have grown more than 20% annually in the last five years (ITU 2017) [1]
- Smartphones (in 2017) have 70% share of the total market of all device types (IDC) [2].
- Quality & performance of the cellular network depends:
  - radio technology,
  - limitations of device hardware
  - wireless link characteristics (e.g interference, fading, etc.)
  - mobility, location and time of the day
  - Infrastructure of Mobile Network Operators (MNO)

Introduction — Motivation

- Mobile-broadband subscriptions have grown more than 20% annually in the last five years (ITU 2017) [1]
- Smartphones (in 2017) have 70% share of the total market of all device types (IDC) [2].
- Quality & performance of the cellular network depends:
  - radio technology,
  - limitations of device hardware
  - wireless link characteristics (e.g interference, fading, etc.)
  - mobility, location and time of the day
  - Infrastructure of Mobile Network Operators (MNO)
- About 30% of cellular measurements from `netradar` [3] experience sudden drops to zero bitrate for($\geq 200\,\mathrm{ms}$).

Introduction — Research Question

What are the factors affecting the throughput and stability of cellular networks?

Introduction — Contribution

Introduction — Contribution

1. Time of a day and the location affect the throughput:
    - Throughput drops during peak hours in cities as congestion increases.
    - Radio technology switches from legacy (UMTS) to advanced (HSDPA) during the course of a day.

Introduction — Contribution

1. Time of a day and the location affect the throughput:
    - Throughput drops during peak hours in cities as congestion increases.
    - Radio technology switches from legacy (UMTS) to advanced (HSDPA) during the course of a day.
2. Predict the probability sudden drops in bit rate in a cellular network with 90% accuracy
    - relying on easily accessible information (e.g device model, location, network technology).

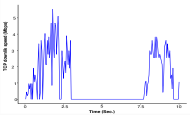
Introduction — Contribution

1. Time of a day and the location affect the throughput:
   - Throughput drops during peak hours in cities as congestion increases.
   - Radio technology switches from legacy (UMTS) to advanced (HSDPA) during the course of a day.
2. Predict the probability sudden drops in bit rate in a cellular network with 90% accuracy
   - relying on easily accessible information (e.g device model, location, network technology).
3. Predict the average TCP download speed based on the first 5 seconds of median bit rate value of throughput.

Methodology

Methodology — Measurement platform

Netradar



- It measures & collects information including throughput (TCP), signal strength, radio technology type, RTT(UDP) etc. towards Amazon Cloud instances & Aalto University servers.
- The measurement server tests the download speed by sending a random data over TCP for 10 seconds.
- During the measurement session, both the client and the server record the number of bytes transferred every 50 ms.

Methodology — Data Set and Measurement Trials

- Based on a longitudinal dataset collected using the `netradar` measurement platform [3].
- Focused on stationary nodes during a ten second measurement session — to minimize the variability that might arise from mobility.
- A year-long measurement data (∼750K) from 3 Finnish MNO.

Network Operator	Total # Of Measurements	LTE	HSPA	HSPA+	HSDPA	UMTS	Others
Elisa	373K	45.75%	8.49 %	14.70%	1.12%	25.43%	5%
DNA	235K	63.30%	7.52%	8.17%	10.69%	0.9%	9.42%
TeliaSonera	140K	34.74%	1.04%	14.27%	1.29%	33.60%	15.06%

Table: Measurement Distribution per radio Technology for each MNO

Data Analysis

Data Analysis — Device Model

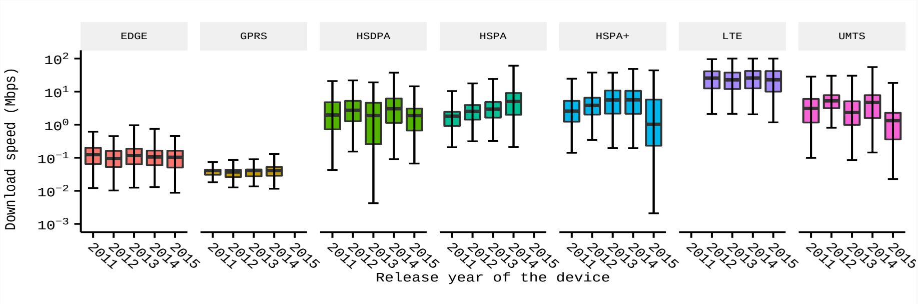


Figure 1: TCP download speed of different device models per network technology.

- The release year of the device models does not correlate to TCP download speed.
- It is not always the newest device model whose TCP download performance is best.

Data Analysis — Mobile Network Operator

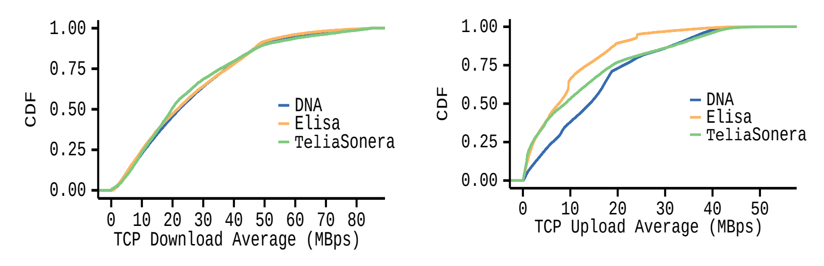


Figure 2: Mean TCP throughput for LTE networks of 3 MNO downlink (left) and uplink (right) speed.

- Clear variation between MNOs on mean uploading speed for LTE.
- MNO's are significant for network performance variation.

Data Analysis — Subscribers Location

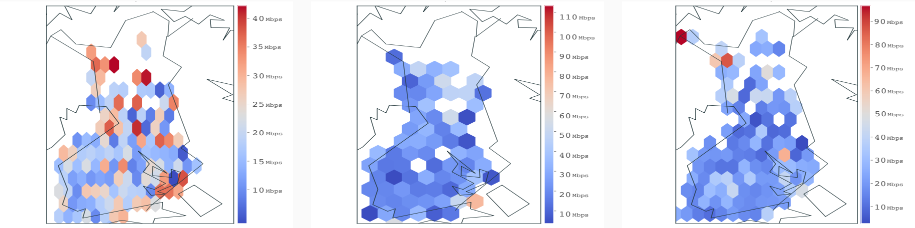


Figure 3: Mean TCP throughput distribution by area in Finland for LTE networks of three MNOs: Elisa (left), DNA (middle), TeliaSonera (right).

- The comparison across MNOs shows a large variation in throughput per locations.
- Users in a metropolitan area & (subscribed to DNA or Elisa) get better throughput than urban areas.
    - Better infrastructure provisioning — base station density — sufficient core network capacity.

Data Analysis — Radio Technology Changes and Time of Day

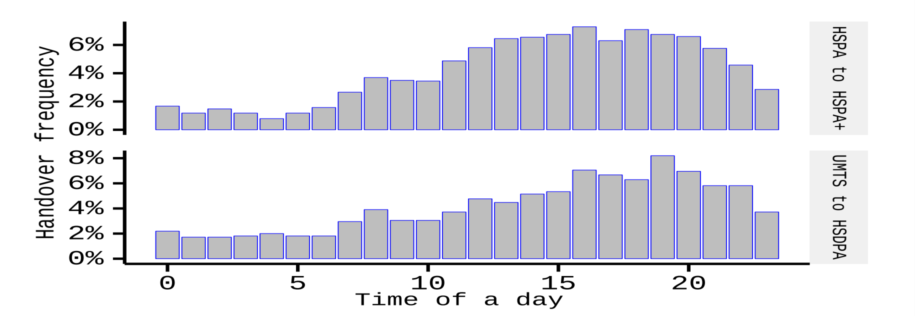
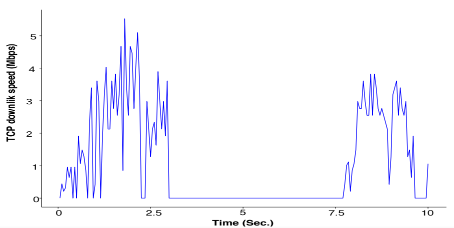


Figure 4: Frequency of radio technology switches over time of day, for the TeliaSonera network (similar to other MNOs).

- The occurrence of switches (from legacy to more advanced technology e.g UMTS to HSDPA) increases during peak hours.

Data Analysis — Network Stability



Classified the data into two groups:

- `dropped`: measurement sessions that experience a sudden dropout >200 ms.
- `non-dropped`: sessions without this phenomenon.

Data Analysis — Received Data per Recording Interval

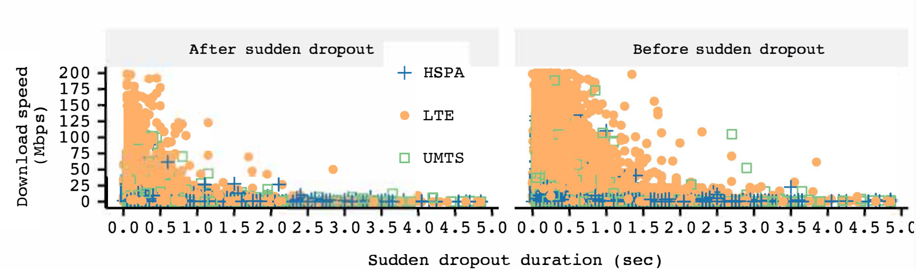
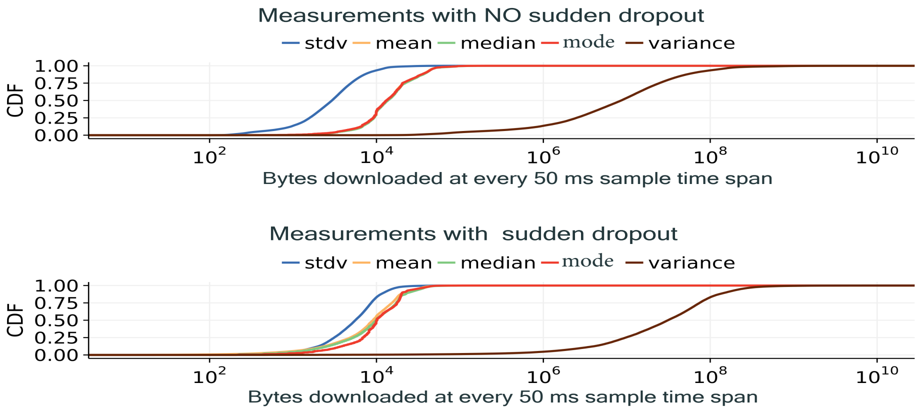


Figure 5: TCP maximum download rate observed before and after a *sudden dropout* of a certain duration ($\geq 200\,\text{ms}$) per radio technology.

- A `sudden dropout` duration that stayed for at least 200 ms does have an impact on download bit rate.
- The impact is visible especially after the dropout period is over (left side of the figure).

Data Analysis — Received Data per Recording Interval



- Mean & median of `dropped` diverge with a relatively higher standard deviation than the `non-dropped` measurements.
- Network inconsistency and jitter is present in the `dropped` measurements than in `non-dropped` ones.

Data Analysis — Received Data per Recording Interval

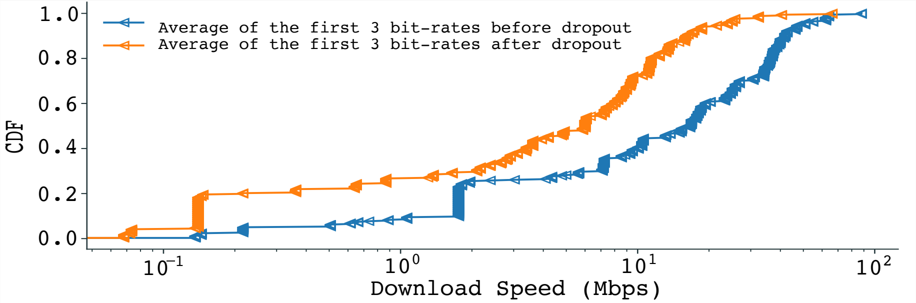
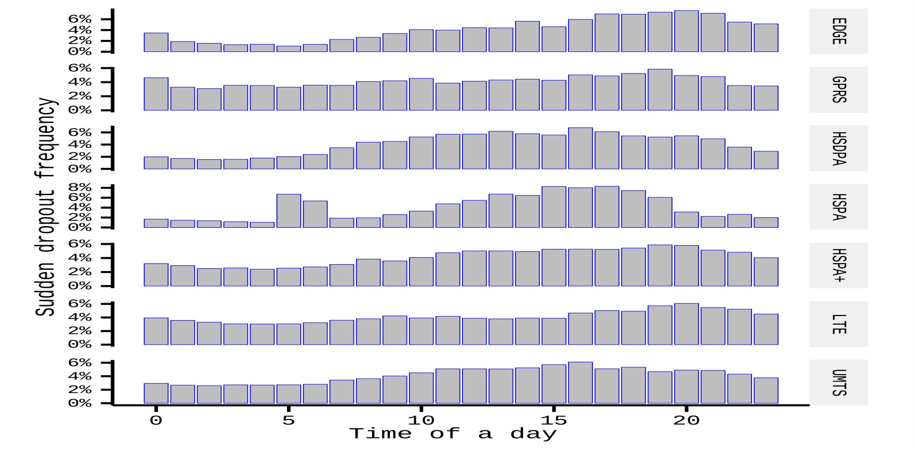


Figure 6: Average of the first 3 bit rates samples before and after a *sudden dropout*.

- The effect of *sudden dropout* is reflected even after the *sudden dropout* (zero bit rate) is over.

Data Analysis — Sudden Dropout by Network Technology



- The sudden dropouts is distributed in all radio technology that has been used.
- Some technologies such as UMTS and HSPA show frequent *sudden dropouts* during daytime.

Data Analysis — Switching Radio Technology

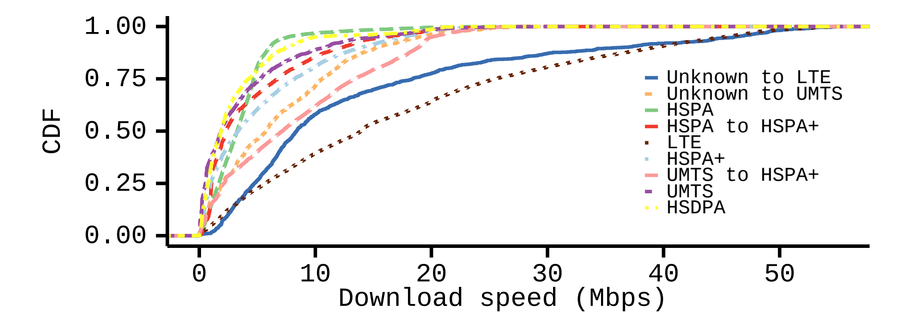
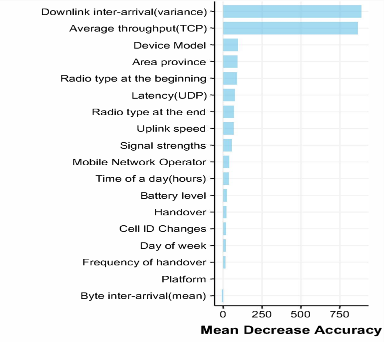


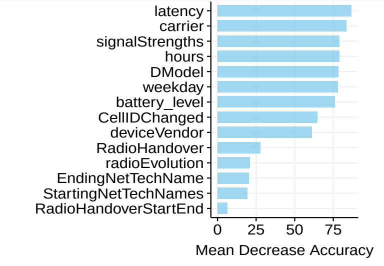
Figure 7: Impact of radio technology switches for download speed.

- When sudden dropout happens a switch in radio technology causes a significant variation in TCP download speed.
  - E.g. a change from UMTS to HSPA+ has better download speed than from HSPA to HSPA+.

Data Analysis — Feature Importance and Selections



(a) with TCP throughput



(b) without TCP throughput

- Latency, carrier network, signal strength radio network technology, time of the day and device model found to be important predictive variables for classification.

Data Analysis — Classification model

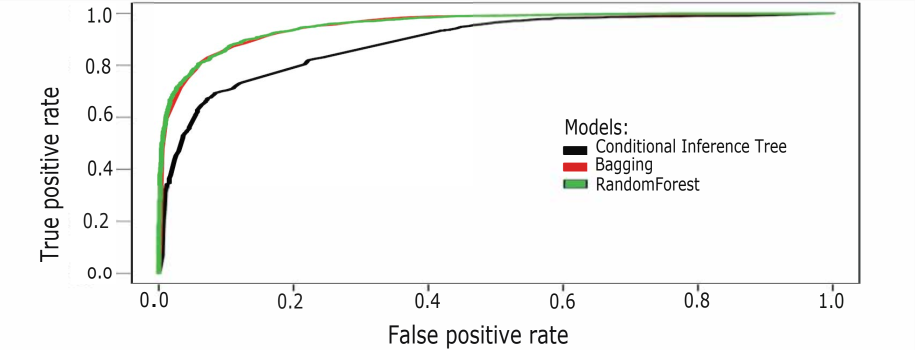


Figure 9: True positive and false positive rates of the three classification models; random forest shows the best Receiver Operating Characteristic (ROC) curve.

- Random forest based classification produces better prediction with accuracy of 90% & error rate of 10.2% on the testing dataset.

Data Analysis — Predicting the Average Throughput

- Prediction of througput is useful (eg. to improve video performance in cellular networks [4]).
- How to predict the overall mean throughput only using the first five seconds of TCP bit rate measurement?
- Train a model using Randome Forest algorithm from caret [5] package.
- The model predict average throughput: using only the first 5 sec. download rates (which would be easily available right after startup) with Root-Mean-Square Error (RMSE) (0.003 Mbps) & 98% R-squared.

Conclusion

Conclusion

Conclusion

1. Throughput observed by a cellular network user depends on various factors.
    - E.g location and time of the day where metropolitan areas during peak hours showed more drops in throughput.

Conclusion

1. Throughput observed by a cellular network user depends on various factors.
   - E.g location and time of the day where metropolitan areas during peak hours showed more drops in throughput.
2. Network stability:
   - TCP being sensitive to losses and jitter $\sim$30% sudden drops to zero bitrate - could create performance degradations.
   - classify stability based on sudden dropouts only relying on easily accessible information.

Conclusion

1. Throughput observed by a cellular network user depends on various factors.
   - E.g location and time of the day where metropolitan areas during peak hours showed more drops in throughput.
2. Network stability:
   - TCP being sensitive to losses and jitter ∼30% sudden drops to zero bitrate - could create performance degradations.
   - classify stability based on sudden dropouts only relying on easily accessible information.
3. Predicting the average throughput:
   - useful to anticipate future performance & to adjust application demands.
   - trained a model that predicts average throughput based on throughput of TCP slow start phase.

Conclusion

1. Throughput observed by a cellular network user depends on various factors.
    - E.g location and time of the day where metropolitan areas during peak hours showed more drops in throughput.
2. Network stability:
    - TCP being sensitive to losses and jitter ∼30% sudden drops to zero bitrate - could create performance degradations.
    - classify stability based on sudden dropouts only relying on easily accessible information.
3. Predicting the average throughput:
    - useful to anticipate future performance & to adjust application demands.
    - trained a model that predicts average throughput based on throughput of TCP slow start phase.
4. Future work extending — our predictive approach :
    - Using Crowdsourcing Data for Adaptive Video Streaming in Cellular Network.

ermias.walelgne@aalto.fi

References

- ITU, “ITU releases 2017 global information and communication technology facts and figures.”
- IDC, “IDC idc 50th anniversary transformation everywhere,” 2017.
- “Netradar measurement platform.” `http://www.netradar.org/`.
- X. K. Zou, J. Erman, V. Gopalakrishnan, E. Halepovic, R. Jana, X. Jin, J. Rexford, and R. K. Sinha, “Can Accurate Predictions Improve Video Streaming in Cellular Networks?,” HotMobile, pp. 57–62, 2015.
- M. Kuhn, “Building Predictive Models in R Using the caret Package,” *Journal of Statistical Software*, vol. 28, no. 5, pp. 1–26, 2008.