Analyzing Throughput and Stability in Cellular Networks

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Introduction
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)

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- About 30% of cellular measurements from netradar [3] experience sudden drops to zero bitrate for ($\geq$ 200 ms).
What are the factors affecting the throughput and stability of cellular networks?
Introduction — Contribution

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.

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).

Predict the average TCP download speed based on the first 5 seconds of median bit rate value of throughput.

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Methodology
Methodology — Measurement platform

- 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.

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

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.
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 (≥ 200 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.
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.
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.
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+.
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.
Prediction of throughput is useful (e.g., 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?


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
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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.

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.

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.


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4. Future work extending — our predictive approach:

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ITU, “ITU releases 2017 global information and communication technology facts and figures.”


