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DISSERTATION TITLE: *On Reliability in Mobile Broadband Networks*

Džiugas Baltrūnas har i sin PhD-grad presentert en langvarig studie om pålitelighet av mobile bredbåndsnett med fokus på den brukeropplevde robustheten og stabiliteten til mobilnett. Studien er basert på flere milliarder datapunkter samlet fra hundredevis målenoder som er spredt rund i Norge og koblet samtidig til to eller flere norske mobiloperatører. Studien viser stor forskjell på pålitelighet mellom forskjellige mobilnett samt mobile- og stasjonære forbindelser.

This thesis presents a framework for measuring reliability in mobile broadband (MBB) networks and conducts a large-scale measurement study of Norwegian MBB networks using Nornet Edge (NNE) – a dedicated measurement platform.

The proposed framework uses end-to-end measurements to assess reliability as experienced by the end user. The framework measures reliability at several levels, from the stability of the network connection to the reliability of the data plane and application layer performance. We believe that this framework gives a good basis for describing the overall reliability of a MBB network.

The study uses the proposed framework to measure the reliability in five Norwegian MBB networks for stationary and mobile connections. The measurements presented here have demonstrated that there are clear differences in reliability between operators, and that these can be identified and characterised by end-to-end measurements. Networks vary in the stability of connections, in packet loss and delay patterns, and in their ability to support popular applications.

For the stationary scenario, we find that most loss is a direct result of radio resource state transitions, both regular and pathological, while the remaining loss is mostly due to activity in the core network. For the mobile scenario, we established that loss in MBB

networks is significant under mobility, and much higher than in the stationary case. In particular, we find disturbances or handovers between different radio access technology is a main cause of loss, accounting for about 70% of the total.

We have shown how end-to-end measurements can give insights into the performance of cellular network internals and be used to identify failures and performance problems that are not necessarily captured by the operators' monitoring systems. Our results motivated one of the operators measured to re-examine its network configuration to mitigate loss caused by state transitions. We further showed that using two MBB connections from distinct operators in parallel can potentially give 99.999% availability. These results build the case for independent end-to-end measurement infrastructures like NNE, which allows correlating measurements at different levels and spot potential problems in MBB networks.

As a step towards a next generation, more decentralised, reliable and flexible and IP-like mobile networks, we presented MULTEX – an approach that transforms an LTE user agent into a multi-homed device with simultaneous access to multiple packet data networks with diverse geographical boundaries. We showed that MULTEX is readily deployable in current LTE networks with no modifications to the existing signalling protocols.