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Fine-grained LTE radio link estimation for mobile phones

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ABSTRACT

Recently, spectrum optimization solutions require mobile phones to obtain precise, accurate and fine-grained estimates of the radio link data rate. In particular, the effectiveness of anticipatory schemes depends on the granularity of these measurements. In this paper we use a reliable LTE control channel sniffer (OWL) to extensively compare mobile phone measurements against exact LTE radio link data rates. We also provide a detailed study of latencies measured on mobile phones, the sniffer, and a server to which the phone is connected. In this study, we show that mobile phones can accurately (if slightly biased) estimate the physical radio link data rate. We highlight the differences among measurements obtained using different mobile phones, communication technologies and protocols. We also provide detailed instructions on how to replicate our measurements and describe alternative measurement setups and their tradeoffs.

1. Introduction

Can we trust mobile phone data rate measurements? This apparently trivial question is key to evaluate the feasibility of the anticipatory networking [1] paradigm and the related future network solutions [2,3]. For instance, exploiting achievable rate prediction to optimize mobile applications [4–6] requires some information exchange between mobiles and base stations so that current decisions (e.g. scheduling, admission control) can be made taking into account the future states of the system. However, while prediction errors have been studied [7,8], the capability of mobile phones to obtain accurate measurements has never been investigated in mobile networks. In addition to that, many recent studies [9–13] rely on crowd-sourced datasets to derive their conclusions without questioning mobile phone measurements accuracy and whether it is possible to aggregate them. Although reliable mobile phone applications to measure the network bandwidth exist [14–16], they focus on end-to-end measurements that do not provide the required level of granularity to enable anticipatory optimization. In fact, while end-to-end data rate is ideal to optimize TCP performance, the resource allocation optimization would rather benefit from the actual radio link data rate between eNodeB and user equipment (UE).

In this paper, we study whether mobile phones can accurately measure LTE radio link data rate and with which granularity (i.e. sampling frequency). To achieve this, we compare the data rate estimates computed at the physical layer of the radio link through a sniffer, at the mobile phone kernel through tcpdump and by a mobile application.

Our study is divided into two measurement campaigns: the first and largest set of experiments consists of burst transmissions, where a small amount of data is sent back-to-back to collect data rate estimates computed by the different entities (i.e., phone, sniffer and server), while in the second set, we evaluate latencies between single data packet transmissions and

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their corresponding acknowledgments (ACKs). These latencies allow us to study the root-causes of differences among the behaviors of different phones. In all the tests, we compared three mobile phones by different vendors and equipped with different chipsets, first performing the test from the server to the phone and, then, in the opposite direction.

The main findings of our study are the following:

1. Mobile phones achieve accurate (> 85%) and precise (> 82%) data rate measurements with as few as 20 KB in the downlink, where accuracy and precision are related to how close the measurement are to the sniffer ground-truth readings.
2. Uplink measurements are less accurate and less precise (65% and 60% respectively in the worst case), because LTE uplink scheduling delay causes a higher variability in the results.
3. Different chipsets exhibit variable biases and performance, thus requiring dedicated calibration to optimize accuracy.
4. Downlink accuracy and precision are linked to the latency measured on the phone: chipsets providing shorter and more deterministic latencies obtain better estimates.

Further, we provide a thorough guide on how to perform similar measurements. We present the state of the art of tools that can be used to assess the performance of LTE components, such as eNodeBs and UEs, as well as discuss the tradeoffs of each approach.

The rest of the paper provides a survey of related work in Section 2, specifies the measurement setup and the devices involved in Section 3, and discusses the two measurement campaigns in Sections 4 and 5. Section 6 summarizes the main findings, while Section 7 specifies how to repeat our measurements and discusses a few setup alternatives. Finally, Section 8 concludes the paper.

2. Related work

A considerable number of recent papers focus on LTE measurements and measurement techniques, but, to the best of our knowledge, none of them rely on accurate LTE scheduling information to validate their findings. Among them, Huang et al. [10] studied LTE performance measured from mobile phone data. In order to obtain a known reference for the results, the authors performed experiments using controlled traffic patterns to validate their findings.

The fraction of LTE resources used for communication is detected in [17] by means of power measurements. The goal of the authors is to evaluate the performance of M2M communications using experimental data. Similarly, RMon [18] is a solution to assess which resource blocks are used by comparing the average power measured over the resource bandwidth with that of the closest LTE reference signals. RMon achieves good performance and robustness, but it can only assess the average fraction of used resources. Hence, it cannot be used to capture the actual base station data rate.

LTEye [19] was the first attempt to decode the LTE control channel to access scheduling information. However the authors found in their later work [18] that LTEye could not provide sufficient reliability and a significant fraction of control messages remain undecoded. To overcome this limitation, we developed a reliable LTE control channel sniffer, called Online Watcher for LTE (OWL) [20]. In our tests, OWL successfully decoded 99.85% of the LTE control messages, thus obtaining a complete log of the eNodeB scheduling. MobileInsight [21] is a mobile phone application capable of accessing LTE control messages directly from the radio chipset and could also be seen as an alternative to OWL. Moreover, a few complete open-source platforms exist to realize an LTE system. Among them, the most advanced solutions are offered by OpenAirInterface [22] and srsLTE [23].

A few papers [24–26] use commercial tools and/or operator network information to evaluate LTE performance. For instance, direct access to network logs is used in [24] to provide a detailed comparison between LTE and UMTS, but since network logs are usually always anonymized (if they are released at all), it is impossible to identify a given device under test among the set of traces. A commercial LTE modem from Teldat is used in [25] to measure application level performance, but this only provides information related to the modem itself. It does not provide resource allocation information about other mobile devices in the same cell. Similarly, a network maintenance tool is used in [26] to analyze quality of service, but such tools only provide compound information averaged over periods of time, which do not achieve the required granularity for our measurements. The vast majority of papers however, just rely on measurement performed using mobile phones or replicated in laboratory experiments. Phone traces are used in [12] to evaluate network performance. The same authors developed a framework [13] to manage mobile phone measurements and a similar project was developed in [9]. In [11], LTE performance predictors are evaluated in laboratory setups. In addition, [27] uses TCPdump traces to perform energy efficiency evaluation of smartphones and [28] studies LTE shared access in a trial environment.

Finally, although not specifically developed for LTE, the following contributions discuss mobile measurements in general terms. The most popular approach is Ookla's Speedtest [14], which can provide a very accurate evaluation of the steady-state rate achievable by long-lived TCP connections. However, Speedtest is both data intensive (with fast connections, one test can consume more than a few tens of megabytes) and cannot provide estimates at the granularity required in this study. A few recent papers [15,16] studied end-to-end achievable throughput, also accounting for inter-arrival times and passive monitoring techniques, but without comparing their findings with ground-truth readings. The accuracy of WiFi measurements performed by mobile phone is studied in [29] based on a timing analysis. However, their results cannot be applied to our scenario for two reasons: WiFi and LTE differs significantly in terms of scheduling and MAC protocols, and tcpdump traces do not provide a reliable ground truth for the physical radio link.