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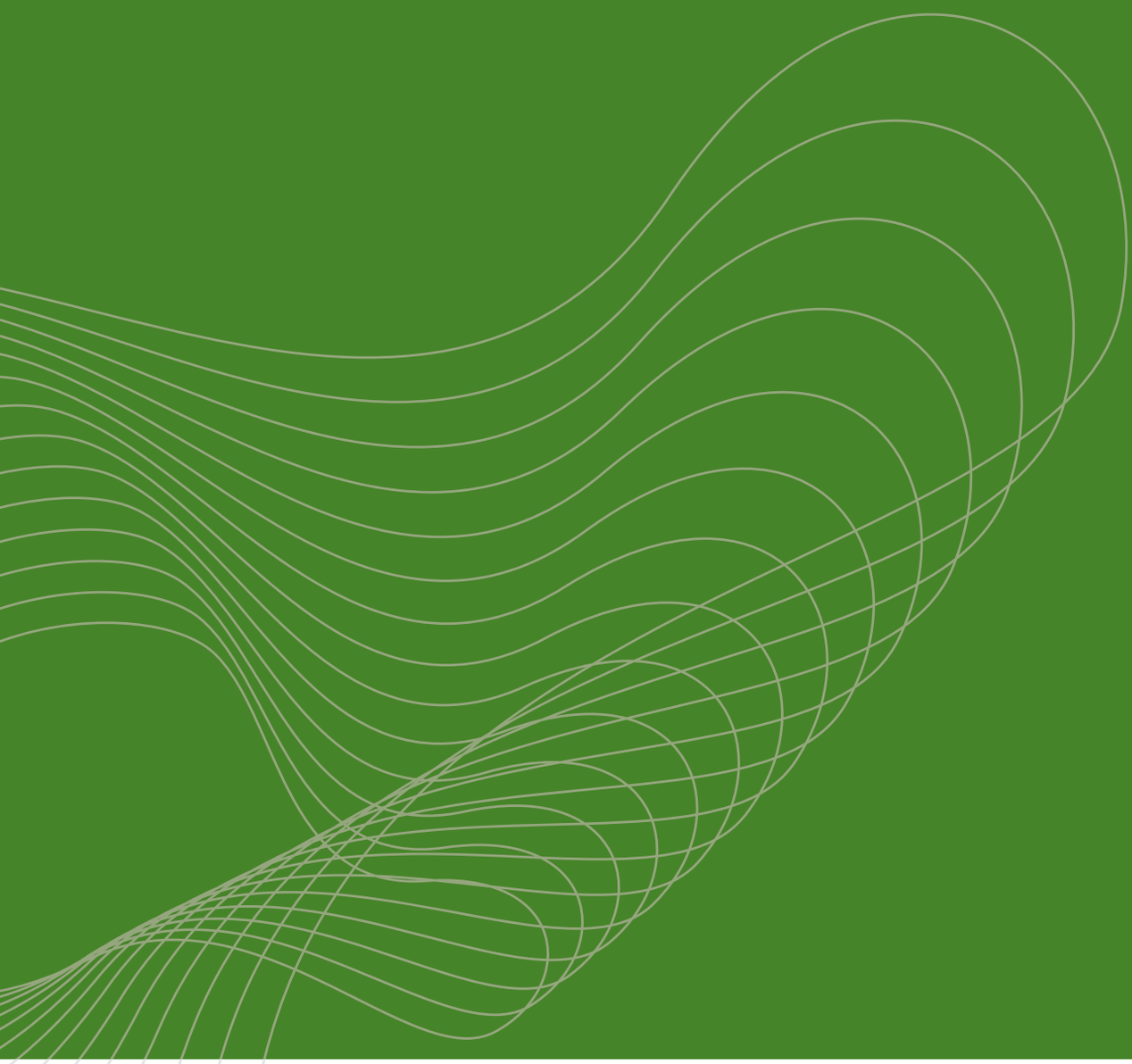
An Explanatory Paper by the NGMN Alliance

User Data Rates in Mobile Data Networks



next generation mobile networks

An Explanatory Paper by
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User data rates in mobile data networks

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1 Introduction

The mobile internet has been a huge success in recent years based on 3G technologies, and next generation technologies such as LTE offer substantially increased peak and average data rates with higher network capacities.

Commonly, the peak data rate is used to characterize the user data rate performance of a technology, but this often does not reflect the data rate users actually experience. The data rate that can be supported over the radio link is usually constrained to a much lower value, with two key dependencies:

- the location of a terminal in a cell affecting the quality of the radio channel
- the loading in the network, influencing the degree of sharing of radio resources with other users of the cell as well as the interference levels.

This paper explains how these dependencies impact the user data rates and shows how a file transfer simulation can be used to characterise the variation in data rates.

2 User data rate dependencies in mobile networks

The user data rate offered by mobile data networks depends upon a large number of different factors, some not related to the radio interface (e.g. backhaul, QoS prioritisation, internet, application server). In this paper we consider the fundamental constraints to the user data rate arising from the radio interface, and how these cause large variations in the data rate depending upon the user location and network load.

Modern mobile networks are designed to maximise performance based upon the following key principles:

- The spectrum is exploited as far as possible by using wide bandwidth channels with the same spectrum being reused in all neighbour cells.
- Cell resources are exploited to the greatest extent by dynamically sharing them across all cell users on an as-needed basis. One user downloading a large file can access all the available cell resources if no one else needs them.

The impact of each of these will be considered in turn below.

2.1 Spectrum reuse in all cells

The reuse of the same spectrum in all cells increases the channel bandwidth and spectrum efficiency; but this also causes a large variation in the quality of the radio channel over the cell area. The achievable data rate for a given bandwidth strongly depends upon the signal-to-interference&noise ratio (SINR) in the channel. The transmissions from a neighbour cell on

the same frequency are generally seen as interference, and therefore a user's SINR strongly depends upon how close he is to a cell border.

To quantify this further, typical mobile radio propagation is such that the signal level decreases by a factor of around 10 when the distance to the serving cell is doubled. Close to the cell site it is therefore quite possible to achieve an SINR ratio of more than 100 (20 dB), because the signal is much stronger than that experienced at the cell border, while the interference from neighbouring sites is weaker. However, at the cell border, the signal from the serving cell and the interfering neighbour are more or less comparable, so that the SINR reduces from 100 to only 1 (0 dB). This is illustrated in figure 1 below.

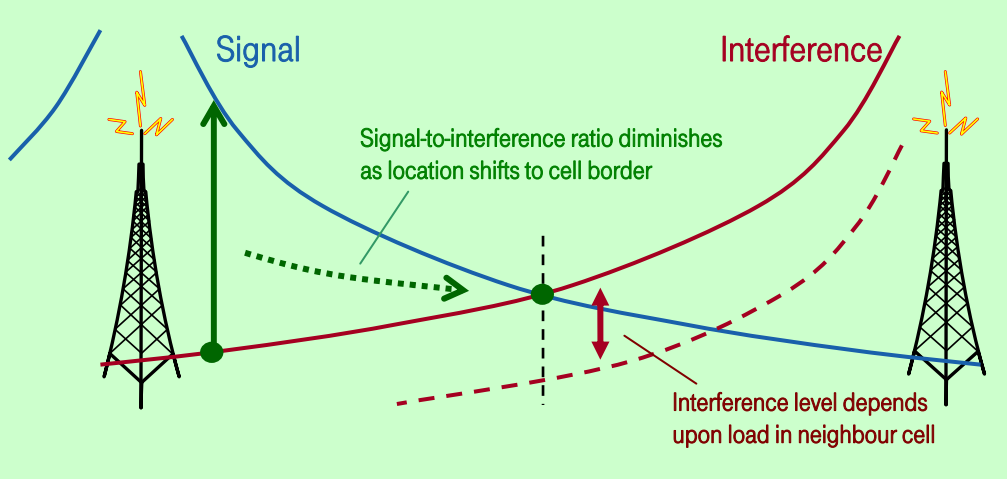

Figure 1 – Variation of signal to interference ratio with location in the cell.

The mobile network applies link adaptation to match the robustness of the link to the quality of the radio link, but this link adaptation provides much lower data rates in poorer radio conditions. The large variation in SINR over the different locations in a cell can alone cause a variation in the user data rate of more than an order of magnitude.

It should be noted that the SINR depends not only on the user location, but also on the instantaneous loading in neighbour cells that determines the level of interference. That is one of two important ways in which loading affects the user data rate. The other relates to the sharing of resources with other users on the same cell, as explained in the next section.

2.2 Dynamic sharing of cell resources

The full and dynamic sharing of cell resources (on downlink, bandwidth & power) fully exploits those resources and thereby enhances the average user experience, particularly at low loading. However, because a user has to share resources with other users, his data rate will depend upon the number of other user simultaneously contending for the cell resources.

The sharing concept is the same as that which drove the development of packet switched networks, and indeed it gives mobile network performance certain characteristics of packet switched networks best described by simple queuing theory. In a cell with a low average utilisation of the available resource, a user can usually expect to be served quickly with the full resources of a cell, and the high data rate provided allows the transfer to be completed

quickly so that the resource freed for others. But then when the utilisation of the cell increases toward 100%, due to increasing load, a user must expect to contend with an increasing number of other users to transfer his data. The user's share of cell resources, and hence the data rate he experiences, falls towards zero as the cell loading approaches its maximum capacity. This is illustrated in figure 2 below.

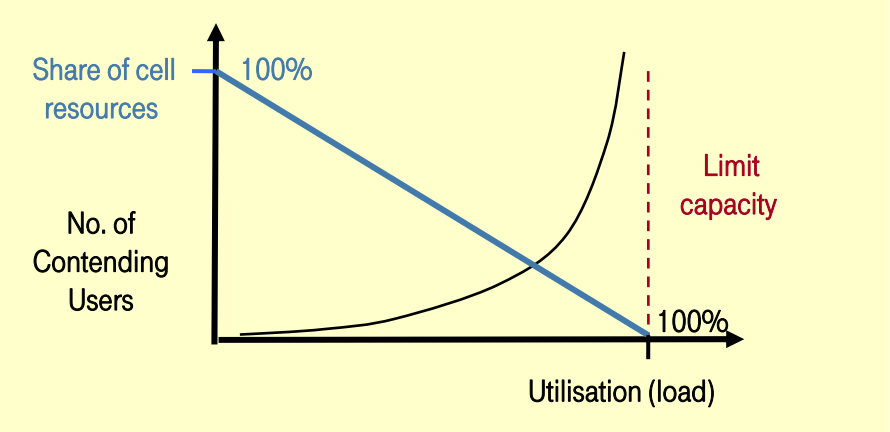

Figure 2 – Sharing of cell resources depending upon load

2.3 Summary of key radio related dependencies

The way the location and traffic load influence the user data rate is summarised in the figure below. The user data rate is determined by two factors: the SINR ratio and the share of cell resources, these factors themselves depending upon the user location and the traffic loading.

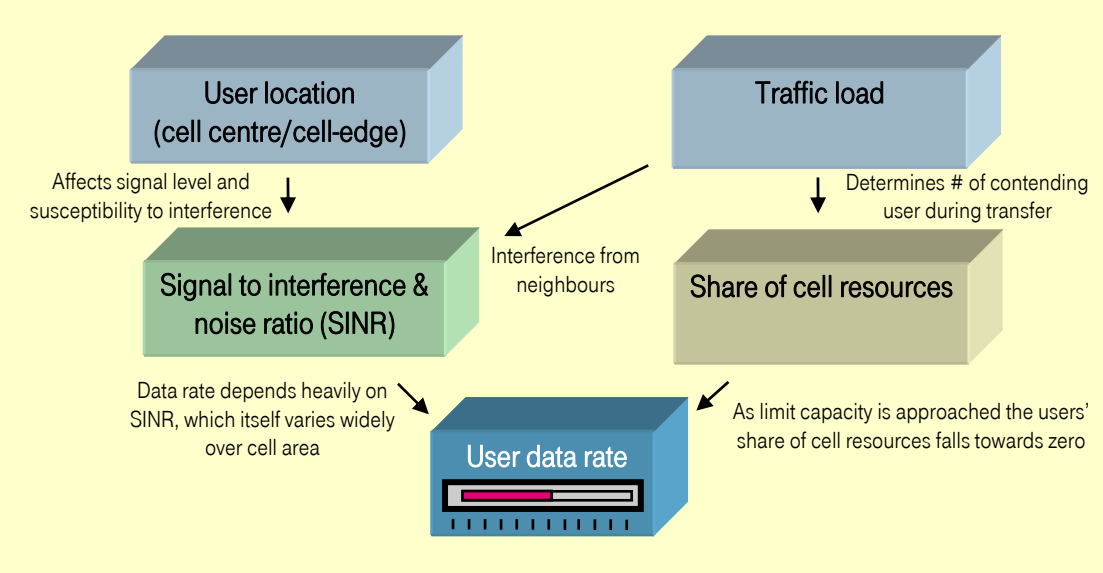

Figure 2 – Illustration of how location and loading impact the user data rate

3 File transfer simulations

File transfer simulations can be used to characterise the user data rate dependencies discussed in the previous section. Recently a large number of such simulations have been performed in an industry wide evaluation of typical user data rate for LTE and HSPA technologies.

Individual simulations model users performing file transfers in a network, at random times and locations but with a predefined average rate of file transfer set-ups reflecting the intended network loading, or cell throughput. For the period of the file transfer the application is assumed to transfer data as quickly as the network allows. A user data rate sample is obtained from each file transfer by dividing the file size by the download time. The user is dropped from the simulation as soon as the data volume of the file is successfully transferred.

An illustration of the results produced by such file transfer simulations is shown in the figure below. For each cell throughput loading level, the simulation produces a distribution of user data rates for all of the file transfers that have been modelled. The data rate that matches or exceeds the data rate of 5% of the samples is considered to reflect the performance of the cell edge users, while the data rate that is exceeded by 5% of the samples is considered to reflect the performance of the cell centre users. The mean user data rate is the average representing the average performance at that particular load. A number of such distributions are collected for different file transfer initiation transfer rates, so that three curves can be plotted for the mean, cell centre and cell edge data rates as a function of cell throughput loading.

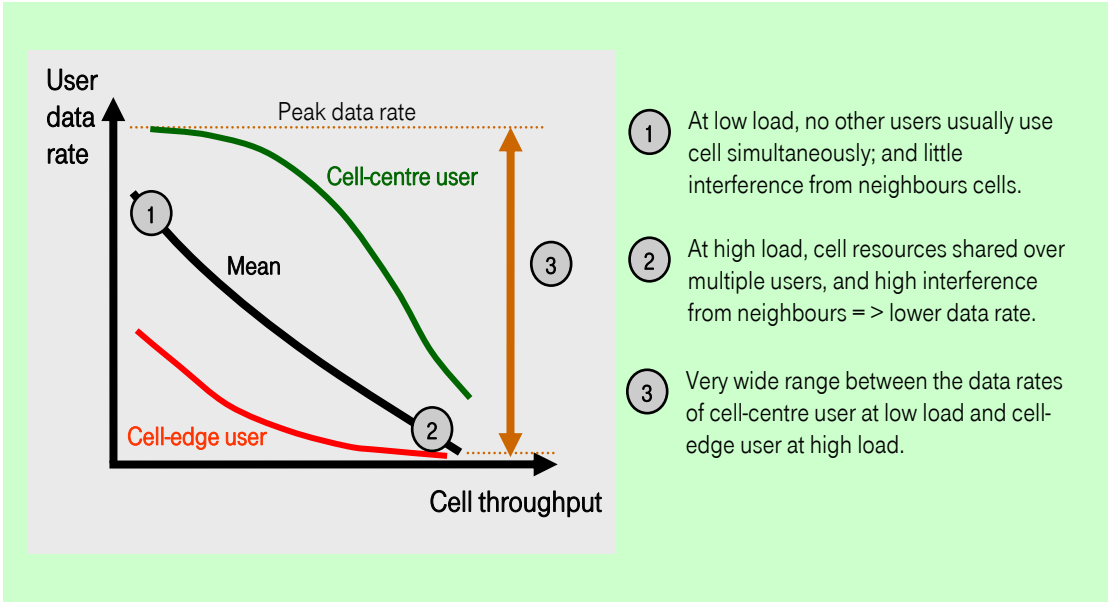

Figure 3 – Illustrative result from file transfer simulations

The results show that as the cell throughput loading increases, the mean, cell edge and cell centre data rate all decrease substantially. Furthermore, at a particular cell throughput

loading a wide spread in performance is seen between the cell edge and the cell centre users.

The peak data rates witnessed by some users at low load might be two orders of magnitude higher than the cell-edge rate in a network with loading approaching the limit capacity. The mean data rate varies widely according to the loading.

In order that the user data rate for different technology options can be compared in a straightforward way, *a typical user data rate* definition has been proposed as representing an indicative user data rate in a reasonably well utilised network. The typical user data rate is the mean user data rate for a cell throughput level that results in a 50% utilisation of the cells resources.

The typical user data rate only represents an indicative performance level of networks at a certain consistent fractional load level, but it cannot be considered representative of all actual networks where a variety of loading levels exist.

4 Conclusions

The substantial improvements on mobile data network performance in recent years have been achieved by full exploitation of spectrum resource and dynamic sharing of cell resources. Unfortunately these same factors also cause a wide variation in the user data rate depending upon the user location within the cell area and the network loading.

File transfer simulation can characterise the variation in user data rate. A large number of such results had been obtained by NGMN for HSPA and LTE in an industry wide initiative.

5 Glossary

3G	3rd Generation
HSPA	High speed packet access
LTE	Long term evolution
NGMN	Next generation mobile network
SINR	Signal-to-interference&noise ratio