Sustainable traffic growth in LTE network

Analysis of spectrum and carrier requirements
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Executive summary

This white paper describes a simplified model for network capacity expansion as a function of current network loading and future traffic growth. The paper shows that the geographical traffic distribution can be modeled with an exponential function. This model is also applied for carrier upgrade calculation.

The paper shows that the maximum Physical Resource Block (PRB) use depends on the targeted user data rate during the busy hour. Ideally, the PRB usage of busy cells should remain below 80% to maintain good end-user performance based on application measurements. High PRB use in busy cells leads to lower user data rates. At the network level, namely for a 24-hour period for the whole network, an average PRB use of 20-25% can be obtained while maintaining acceptable performance during the busy hour. If we also want to provide high data rates during these busiest hours, the average PRB utilization must be lower and the base station capacity needs to be upgraded earlier.

The paper also demonstrates that LTE networks can carry more traffic by adding more carriers to the existing LTE sites, and by adding LTE to those sites where LTE has yet to be installed. Once these solutions are exhausted, the network capacity can be further increased by utilizing small cells, beamforming and new spectrum options with 5G.
Introduction

This Nokia white paper describes the network capacity expansion requirements as a function of traffic growth. The starting point is LTE coverage using just one frequency band. When the traffic grows, the capacity is expanded using carrier upgrades on the congested sites. The number of required upgrades depends on the traffic growth and also on the geographical traffic distribution. This paper presents a simplified model for traffic distribution based on live network measurements. When the entire spectrum is used and no more carriers can be added, network densification is required in the busiest areas. This paper shows how many sites will be spectrum-limited as a function of traffic growth. It will also show how many new carriers need to be added to the network to support traffic growth. The various phases of the network evolution required are illustrated in Figure 1.

Coverage phase

Carrier upgrade phase

Network densification phase

Figure 1. Network upgrade phases

Capacity upgrade modeling

We assume that a new carrier is added to the site if the average busy hour Physical Resource Block (PRB) usage gets high. A carrier upgrade refers to adding a new frequency to the base station site. If we want to provide a higher user data rate, then the network upgrade is required at PRB usage levels of 40-50%. If we allow user data rates to be impacted during the busy hour, the PRB usage can be increased to 90% or even 100%. We further assume that the busy hour carries 70% more traffic than an average hour, meaning that the busiest hour accounts for 7% of the traffic over a 24-hour period. We also assume a detailed geographical traffic distribution model where 17% of the sites account for 50% of the data volume, and that LTE spectral efficiency improves by 30% because of new features such as interference cancellation, interference coordination, 256QAM and MIMO evolution. These assumptions are shown in Figure 2.
When network loading increases, user data rates decrease. If we wish to provide high user data rates, the capacity upgrades need to be planned for at a low load. If we allow lower user data rates during the busy hour, higher network loading is allowed. Figure 3 illustrates an example of a relationship between the data rate and PRB utilization in 20MHz LTE. 40% PRB utilization provides an average data rate of 10Mbps, while 90% utilization gives 5Mbps. In other words, the maximum allowed PRB usage depends on the required user throughput, meaning there is no single value which is correct for all operators. The curve also depends on the RF quality and LTE bandwidth: the data rate would be lower in case of a large overlap between cells, and the data rate would also be lower with 10MHz LTE. On the other hand, with carrier aggregation the data rate would be higher.

For this paper we chose two criteria to use for carrier upgrades, namely 40% PRB utilization for high performance networks and 90% PRB utilization for capacity-optimized networks.
In order to better understand the maximum practical loading, we must examine the impact of loading on application performance. Figure 4 shows the distribution of web page download times with different PRB utilization, measured over 15 minute periods. The download time remains quite constant as long as the PRB utilization remains below 80%. When PRB utilization is between 90-97%, the median download time increases from 3.6 to 6 seconds. When PRB utilization is higher than 97%, the download time is almost 8 seconds. Figure 5 shows a similar trend; here the web page download time increases from 6 seconds at low loading to 10 seconds at high loading. These results illustrate that PRB loading should preferably remain under 80% if we want to maintain good performance for web page applications.

Figure 4. Web page download time distribution under different PRB loads for a typical mobile optimized web page (approx. 300kB)

Figure 5. Web page download time distribution under different PRB loads for a simple web page with single DNS query
Traffic distribution modeling

We would like to have a simple formula for modeling the geographical traffic distribution. Figure 6 illustrates an example of a distribution from a live network. Each blue dot represents one cell per day. The X-axis shows the traffic per site compared to average traffic. For example, the value of 3.0 means that there are 4.2% of sites which carry three times more traffic than the average site. We have used an exponential trend line (marked in red) that nicely matches the real distribution. We repeated the same exercise in another network and the results are shown in Figure 7. Both curves represent the traffic distribution over the whole network. We used the following approximation formula for the traffic distribution “\( \exp(-x) \)” where \( x \) is the site traffic vs the average site; the output is the probability.

\[
y = 1.0945e^{-1.087x}
\]

Figure 6. Traffic distribution in live network vs exponential modeling (blue dots = live cells per hour. Red curve = trend line)
The underlying reason for the exponential distribution is expected to be as follows. The packet call arrival process and traffic volume both exhibit a Poisson distribution. This accurately describes the arrival process because the number of packet calls is large and they originate from a large group of users. From theory we know that the exponential distribution is the probability distribution that describes the time between events in a Poisson process. Therefore, it is an expected that the traffic and PRB usage distributions follow an exponential model.

Figure 8 shows the cumulative traffic distribution with this model: 50% of the traffic is collected by 17% of the busiest sites. There are some differences in the traffic distribution between networks depending on the country geography and population distribution. In some networks 50% of the traffic comes from more than 20% of the base stations while in other networks the traffic comes from clearly less than 20% of the base stations.
The traffic distribution over a 24-hour period is shown in Figure 9. Busy hour typically takes place in the evening, and carries 6-7% of the daily traffic. That means the busy hour carries 60-70% more traffic than an average hour, and substantially more traffic than low traffic hours overnight. Therefore, the network utilization remains low during the night time.

![Traffic distribution over 24h period](image)

**Figure 9. Traffic distribution over a 24-hour period**

**Carrier upgrade requirements with current traffic**

We use the above described modeling to estimate network upgrade requirements. We first present the starting point by estimating the number of sites where multiple carriers are needed as a function of network loading. Figures 10 and 11 show the cases where the upgrade is done with 90% and 40% PRB usage, respectively. The X-axis shows the average PRB utilization for the whole network during a 24-hour period. If the upgrade trigger is 90% PRB utilization and the average PRB utilization is less than 10%, then practically there is no need for a second carrier to deal with capacity. If the PRB utilization is 15%, then 3% of the sites would need two carriers. With 20% utilization, 7% of the sites need two carriers. Some three-carrier sites will be required if the PRB utilization grows above 25-30%.

If the upgrade trigger is 40% PRB utilization, the second carrier additions are triggered at 10% average PRB utilization, while the third carrier adds at 20% PRB utilization. It is clear that the PRB usage level for the upgrade trigger makes a major impact on the required carrier additions.
Figure 10. Percentage of required multicarrier sites as a function of average loading (90% PRB trigger for the carrier upgrade)

Figure 11. Percentage of required multicarrier sites as a function of average loading (40% PRB trigger for the carrier upgrade)
Carrier upgrade requirements with future traffic

We will next analyze the network requirements if the traffic grows by a factor of seven. We selected this growth factor because the typical assumption is that mobile data will grow by a factor of seven from 2016 to 2020-2022. We also assume that the LTE spectral efficiency grows by 30% during the same period. First let’s examine the case where the upgrade is triggered at 90% PRB utilization. Figure 12 shows the amount of multicarrier sites required in the network as a function of today’s loading. Figure 13, meanwhile, shows the cumulative plot where 2CA includes all sites with at least two carriers.

If the average PRB utilization is 10% today, then 37% of the sites will need at least two carriers after traffic increases sevenfold. On the other hand, it means that 63% of the sites will not need any capacity upgrades. 13% of the sites need three carriers and 4% of the sites need four carriers. If the starting point is 20% PRB utilization, then at least two carriers are needed at 61% of the sites, three carriers at 35% of the sites, four carriers at 21% of the sites and five carriers 12% of the sites. Many operators will have enough spectrum by 2020 to deploy five carriers. 7% of the sites would need a sixth carrier, so some local capacity solutions may be required in the hot spots; these could mean macro cell sectorization or small cells.

![Number of Carrier Aggregation (CA) sites](image)

Figure 12. Percentage of required multicarrier sites as a function of average loading, if the traffic grows sevenfold and the spectral efficiency improves by 30%. The upgrade trigger is 90% PRB utilization.
Figure 13. Same plot as the figure above but 2CA now includes all sites with at least two carriers, 3CA includes all sites with at least three carriers, etc. (cumulative plot). The upgrade trigger is 90% PRB utilization.

Figure 14. Percentage of required multicarrier sites as a function of average loading, if the traffic grows sevenfold and the spectral efficiency improves by 30%. The upgrade trigger is 40% PRB utilization.

The graphs look completely different if the upgrade is triggered at PRB 40% (see Figure 14). The number of 6CA sites already increases at the current PRB utilization of 10%, indicating that we are running out of spectrum. 65% of the sites need at least two carriers.
Figure 15. Same plot as the figure above but 2CA includes now all sites with at least two carriers, 3CA includes all sites with at least three carriers, etc. The upgrade trigger is 40% PRB utilization.
Summary

This paper describes a simplified model for network capacity expansion as a function of the current network loading and future traffic growth. The paper shows that the geographical traffic distribution can be modeled with an exponential function. This model is further used for carrier upgrade calculation.

The paper shows that the maximum PRB utilization depends on the targeted user data rate during the busy hour. High PRB utilization in busy cells leads to a lower user data rate. If we want to maintain an attractive application performance, the PRB utilization should remain under 80% in the busy cell. This typically corresponds to an average PRB utilization of 20-25% for a 24-hour period for the whole network.

This model can be used to predict the required network investment as a function of traffic growth.
Further reading

- White paper “LTE-Advanced Pro - Pushing LTE capabilities towards 5G”
- White paper “LTE-Advanced Carrier Aggregation Optimization”
- White paper “LTE Multiantenna optimization”
- White paper “Mobile Broadband with HSPA and LTE – capacity and cost aspects”

Abbreviations

CA  Carrier Aggregation
CoMP  Coordinated Multipoint
CQI  Channel Quality Indicator
MIMO  Multiple Input Multiple Output
PRB  Physical Resource Block