Summary

Network densification is the evolutionary process that contributed the most during the last decades to allow radio access networks (RANs) cope with the exponential growth in traffic and number of users. Network densification consists in a significant increase in the number of base stations (BSs) that offer service over a given area. This implies a progressive reduction of the area of cells, leading to the concept of small cells (SCs), and possibly to the coexistence of overlapping layers of BSs with large coverage (macro BSs) and SC BSs. Expectations for the deployment of SC BSs were extremely high, but in practice deployment has been limited because of cost and practical difficulties in identifying and instrumenting SC BS sites. In addition, the intrinsic variability in time and space of the traffic demand in a RAN creates traffic peaks that move during the time, thus making the utilization of SC BSs high only for possibly short periods.

To improve SC BS deployment cost and utilization, in this dissertation we advocate the introduction of mobile SC BSs carried by vehicles, exploiting the correlation between density of vehicles and peaks of data traffic, and we quantify the benefits of the proposed approach.

After discussing the issues related to the evolution of RAN architectures in the last decades (Chapter 1), we discuss in some detail the opportunities and challenges inherent in RAN densification exploiting SC BSs on vehicles (Chapter 2). Next, we exploit available real data to quantify the correlation in time and space between vehicular traffic and data traffic in cellular networks (Chapter 3). Our results indicate that correlation exists, as expected, even if the available data for vehicular traffic mostly refer to commercial vehicles, that correspond to a small fraction of vehicles on the road, and may not be fully representative of the density of vehicles on the streets of a large metropolitan area. For example, we observe high values of vehicular traffic early in the morning, when many van deliveries occur, and less traffic in the typical rush hours of employees and students. Nevertheless, correlations tend to be higher in dense urban areas and during high-demand time periods, where and when RAN densification is most needed.

After this preliminary study, we delve into the analysis of the performance of a RAN exploiting SC BSs carried by vehicles. We first study the achievable throughput and fairness in some areas of the city of Milan, Italy (Chapter 4), comparing the maximum throughput that can be obtained with traditional fixed macro and SC BSs to the one achieved with the same fixed macro BSs complemented with mobile small cell base stations. We perform our analysis at different times of the day, using real data for both telecom and vehicular traffic. As an example, studying the main railway station area in Milan, Italy, we see that the use of mobile SC BSs achieves throughput gains up to 120% over fixed access infrastructures with only macro BSs, and equivalent throughput to the deployment of fixed SC BSs.

In addition to the computation of the maximum achievable RAN throughput, we also look at the throughput that maximizes the end user proportional fairness. The next step of our analysis looks at the issues posed by the wireless backhaul connection from mobile SC BSs to the fixed part of the RAN, which is possibly one of the most delicate issues in RAN architectures exploiting mobile SC BSs.

While in the initial throughput analysis we assumed the availability of an ideal link between mobile SC BSs and the macro BS (i.e., a link with unconstrained bandwidth, and no interference with transmissions to/from end users, which could correspond to a millimeter wave connection between mobile SC BSs and macro BS), in this refined analysis we look at simpler technologies for the implementation of the wireless backhaul link. In particular, we look at two alternatives.

1. Out-band backhaul: The link between macro BSs and mobile SC BSs exploits a dedicated bandwidth (or dedicated time slots), different from the one used to connect end users to either mobile SC BSs or macro BSs, so that backhaul transmissions do not interfere with transmissions to/from end users.
2. In-band backhaul: The link between macro BSs and mobile SC BSs exploits the same bandwidth and time slots as transmissions to/from end users. This means that backhaul transmissions and transmissions to/from end users can interfere with each other. The resulting throughput values (presented in Chapter 5) are lower than in the ideal case, as expected, but comparable to the ones obtained with fixed SC BSs, thus proving that the option offered by the exploitation of mobile SC BSs can be an interesting approach for RAN densification with high efficiency at reduced cost. Finally, we summarize our findings and discuss a number of possible directions for further steps in this research topic (Chapter 6).