Demo Abstract: An Open Source Toolchain for Planning and Visualizing Highly Directional mm-Wave Cellular Networks in the 5G Era

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***Abstract*—We demonstrate the first open source toolchain for studying and visualizing the coverage of highly directional mm-wave cellular networks. Based on realistic ray tracing simulations, our framework enables the user to study the expected performance and robustness of mm-wave deployments in a near real-time fashion. A modular software architecture makes the toolchain easily extendible with new statistics and visualizations.**

I. Introduction

The emerging 5G networks employing mm-wave technology will be *fundamentally different* from their microwave counterparts [1], [2]. In particular, the use of highly directional antennas with dynamic beamsteering and environment-dependent propagation characteristics will make network planning much more complex than for present-day radio access technologies, rendering existing planning tools obsolete. In this demonstration, we present a first comprehensive toolchain integrating computationally efficient yet accurate *propagation prediction* with a suite of visualization and planning routines, enabling the user to study the expected behavior of mm-wave networks in a near real-time fashion. In particular, our solution enables *orders of magnitude* faster studies of the impact of realistic technology limitations on the performance of 5G networks compared to conventional tools such as WinProp [3], bringing down the needed computational times from days or weeks to minutes. Our toolchain is based on a highly modular and extendible design, with carefully designed interfaces between components and well thought out data formats, making it easy to incorporate new statistics and visualizations. The software, with video demonstration, is available at [4] via *open source* license, enabling the research community and industry to benefit from and extend our framework.

II. Demonstration Functionality: Planning and Visualizing 5G Networks

The demonstration consists of the user being able to visualize the effects of the network configuration and the urban environment on the coverage and performance of a 5G mm-wave network using a *highly interactive* user interface, enabling exploration of the design alternatives in a *near real-time* manner. Due to the special nature of mm-wave networks, the metrics of interest for network coverage differ significantly from those used in classical cellular networks, and this is reflected in all design aspects of our toolchain. In particular, the effects of dynamic beamsteering of highly directional antenna beams must be considered upfront (cf. planning coverage for static deployments with wide-sector antennas used in today's microwave cellular networks). Namely, uniquely to directional mm-wave networks, it is crucial to consider both achievable coverage and its *robustness*, in terms of secondary coverage and beamsteering opportunities for e.g. resolving link blockage and misalignment.

The dynamic nature of the beamsteering configuration also makes it prone to errors, resulting in imperfect beamsteering configurations where the receiver and the transmitter beams are subject to *misalignments* [5]. Further, the instantaneous network coverage (i.e. at an instant of time with a particular beamsteering configuration) differs remarkably from the *achievable* system level coverage (defined by the highest SNR at a given client location over all possible base stations and beamsteering configurations). Our toolchain explicitly computes and visualizes such alternative networking perspectives and the relevant coverage metrics, to give rich insight into the design and performance of mm-wave cellular deployments.

Fig. 1 illustrates the user interface of our toolchain, showing for an example network configuration of 64 base stations the achievable coverage (upper left panel), example instantaneous coverage (lower right panel), as well as an example of a robustness metric (number of potential serving base stations) in the upper right panel. Each of the panels contains several tabbed views, providing visualizations of alternative performance metrics (maps of RSS, SNR, throughput, coverage, serving BS and nature of the coverage, i.e., whether direct line of sight or through reflections, for achievable coverage; number of available base stations and antenna orientations for robustness; and SNR maps for studying misalignment). The panels are interactive, e.g. selecting any client location allows the user to explore in detail how the coverage is achieved there, visualizing different feasible propagation paths at a given location. The tool also provides numerous options for modifying network design parameters in an interactive fashion. This is especially important for exploring the potential design space

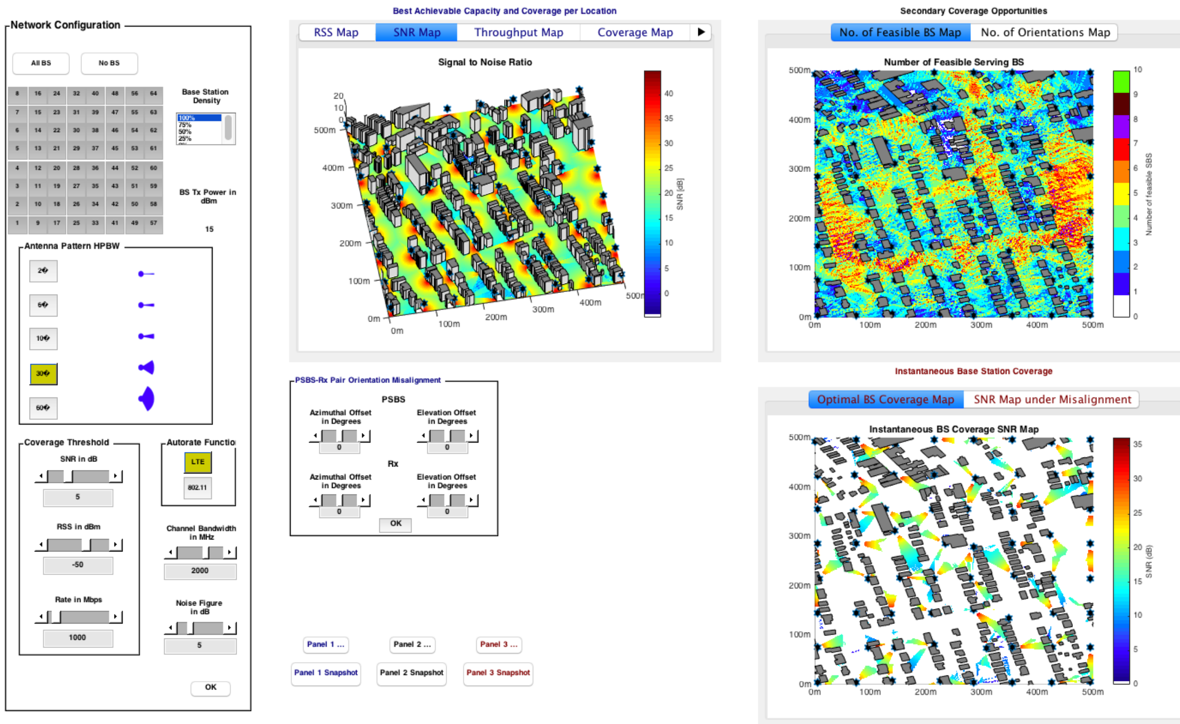

Fig. 1. Planning tool GUI, illustrating different coverage and robustness metrics to characterize mm-wave network performance.

of mm-wave networks, where no leading cellular standards have emerged yet. Examples of such configurable parameters include the channel bandwidth, antenna patterns, and the auto-rate function mapping SNR to an achievable client data rate. The latter is especially important for exploring the realistic potential of mm-wave networks, as solely considering SNR values might be misleading due to the extreme range achieved by directional antennas.

In summary, our toolchain is *highly complete*, enabling near real-time computation and visualization of all major aspects of mm-wave coverage, from achievable system-level coverage to detailed diagnostics on the effects of practical beamsteering impairments on individual links.

III. Implementation Details

Our main objective was a completely modular and extendible design, which we achieved through the use of well thought out interfaces and rich intermediate data formats that make near real-time computation of diverse statistics possible within the framework of the modular architecture in Fig. 2. For example, in existing tools such as WinProp, ray path information is discarded after final RSS/SNR maps are calculated. This would make it necessary to run dedicated ray tracing simulations for each possible beamsteering configuration, e.g. assuming 30° antennas at the base stations and the client receiver would require at least 36×36 individual ray tracing simulations of typically a few hours each. Instead, we store raw ray path information by building a dedicated storage path between the ray tracer and our visualization tools, including sophisticated preprocessing. This allows us to run ray tracing

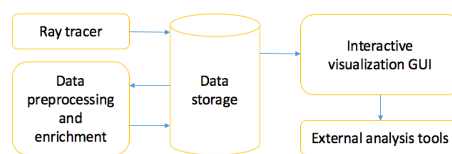

Fig. 2. Software architecture of the planning tool.

just once, and impose the effects of antenna patterns and orientations in postprocessing, in a matter of minutes. Carefully designed storage formats enable a fast recomputation of all the metrics of interest when any of the parameters are changed (with explicit tracking of dependencies between quantities being computed to reduce the computational burden), resulting in an almost real-time user experience. Standard data formats are supported throughout, e.g. building data is read in as a shapefile, enabling the use of openly available real world data sets from, e.g., NYC Open Data initiative.

References

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