CHALLENGES AND OPPORTUNITIES OF D2D NETWORKS

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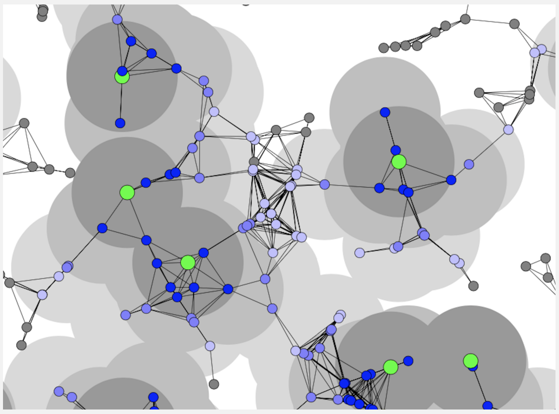
Relevance:

The steadily increasing demand for fast and reliable data exchange in communications systems presents network operators worldwide with major challenges, but also opportunities. A very important aspect of this is the strongly increasing use of *connected machines* as part of the *internet of things* (IoT) as well as *smart devices* such as mobile phones, tablets or *self-driving cars*. This is also reflected in the 5G specification and in the negotiations for subsequent standards, which envisage faster connections, higher throughput, more capacity over enhanced mobile broadband, and highly reliable, low-latency communications to enable the system to support time-critical applications such as car-to-car transmissions as well as inter-machine connectivity. In this context, *device-to-device* (D2D) communications is considered one of the key concepts as it permeates a wide range of use cases. On the one hand, D2D systems have the potential to relieve today's cellular networks from at least some of the system's load. On the other hand, D2D communications can provide, for example, faster and more robust connectivity. However, from an operator's perspective, D2D systems are much less controllable than traditional cellular networks, due to their dependence on individual user behavior. This lack of control is exacerbated when devices are mobile and the system is very dense due to the widespread use of connectable devices. Therefore, to help predicting the performance and vulnerabilities of D2D systems, detailed and *comprehensive probabilistic modelling and analysis* is essential.



Realization of a device-to-device (D2D) augmented dynamical connectivity network.

Mathematical Innovation:

Within the MATH+ ecosystem and together with our collaboration partners, both from academia and industry, we have developed and analyzed complex multi-layered models for dynamical D2D systems using tools from *stochastic geometry* and *statistical physics* [3, 4, 5, 6, 8, 9]. Our main mathematical contributions concern the *phase-transition behavior* of *percolation systems* in the continuum, which feature *long-range correlations*, *interference constraints* as well as *random environments*, and the analysis of *probabilistic dynamics* on *spatial random graphs*.

Application:

In close contact with our industry partners from ORANGE, we have isolated a number of *key challenges and opportunities* for future D2D systems, including questions of *connectivity*, *data throughput* and *decentralized malware protection*. Using advanced hybrid models that capture environment constraints, individual user behavior and further collective uncertainties, we were able to *rigorously derive thresholds* for satisfactory system performance and present supporting *numerical case studies* in a wide range of parameter settings [2, 7]. This allows network operators to accurately predict the quality of service of pure D2D systems as well as D2D-augmented cellular networks. As an example, in [1], the effect of a decentralized malware attack on a mobile pure D2D network is evaluated both in the presence and absence of counter measures. As one key finding, we could isolate regimes in which a malware outbreak becomes unstoppable if the decentralized patching scheme only acts on previously infected devices.

Outlook:

The use of probabilistic methods, e.g., point-process and large-deviations theory, for the modelling and analysis of complex decentralized communication networks has recently opened several doors for new applications, highlighting its great potential to better understand, predict and design such systems. Using our extensive expertise in this domain, in the new MATH+ project *Data transmission in dynamical random networks* we intend to focus on the distribution of data in spatial D2D systems by considering contact times between network components subject to randomness. Additionally, we investigate survival and extinction of viruses via contact processes on a very large class of spatial random graphs that also reflect individual properties of the network agents and derive, e.g., their first-contact distributions.

Selected MATH+ References:

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