Flexible scalable solutions for dense small cell networks

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Abstract— **This paper addresses challenges when designing wireless systems towards the communication needs of society in 2020. Globally people increasingly depend on wireless communications and require significantly improved performance and services in the years to come. Traffic volumes are increasing exponentially, up to 1000-fold in the current decade, at the same time the cost-per-bit and energy consumption should decrease. In this paper we address several trends with their technical challenges and solutions that are faced while realizing these future systems Technical components that may be needed include: support for dense small cells, increased and more flexibly available spectrum, advanced interference cancellation techniques, and very large antenna arrays.**

Index Terms— **Future cellular networks, Heterogeneous network, Spectrum, Interference cancellation, Antenna array, Channel modeling.**

I. INTRODUCTION

Globally people increasingly depend on wireless communications and require significantly improved performance and services of these systems in the years to come. Wireless communications is impacting everyday life in an increasing manner with increasing use of wireless services in the various aspects of life.

Traffic volumes are expected to increase exponentially, up to 1000-fold in the current decade, at the same time the cost-per-bit and energy consumption should decrease. Advances in wireless technologies are needed to meet these challenging objectives, including much denser small cell networks and the need for new approaches for more efficient use of spectrum. New use cases and broadening of existing ones leads to a need to widen the range of supported features. These trends lead to efficient, scalable and versatile networks. *Efficient* in order to meet the increasing performance targets under cost and energy constraints; *scalable* so that a wide range of requirements can be met regardless of traffic volumes; and *versatile* supporting a significantly diverse set of requirements. An increasingly important requirement is that all these developments need to happen in a sustainable way, contributing positively in other areas of life and business.

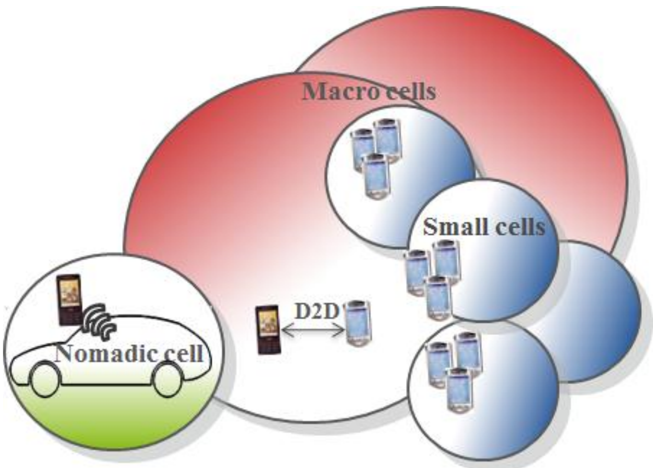

Figure 1. Illustration of a 2020 cellular network deployment.

In this paper we address several trends and related technical challenges and solutions that need to be faced while realizing these future systems, including:

- A strong increase in the number of connected devices
- Networks becoming much more dense
- Use of additional spectrum either in new bands, and possibly even under new rules
- Specific technological advances to improve the overall system efficiency like:
  - Interference cancellation
  - Advanced antenna systems

On top these technical enablers we will be able to develop wireless systems meeting the communication needs of the society towards 20202

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II. Strong increase in the number of connected devices

As the world becomes more and more connected there will be more and wireless devices in our proximity, next to human centric communication also machine type communications is gaining importance, for example in *Internet of Things*. These devices range from very simple sensors to advanced mobile phones, tablets and computers. Efficient discovery of all relevant devices in the proximity of a mobile device is becoming a challenging task in such a setting. Communications requires scalable and power-efficient solutions; especially simple sensors will be highly constraint in terms of available processing power and battery capacity.

Different communication needs exist for sensors; some may infrequently report over large distances in for example telemetric applications or fleet management systems. Others may communicate over short-range information to devices in their immediate vicinity.

III. Ultra-dense networks

Infrastructure densification will continue to be the main driver to address the traffic demands of future communications. In addition, Heterogeneous networks (HetNets) become more dynamic with the introduction of moving networks and ad-hoc social networks. However, dynamic and ultra-dense deployments of HetNets raise many new challenges e.g., related to interference, mobility and backhauling. It is required to design novel network-layer functionalities to maximize the performance besides the design of the current physical layer.

There are existing interference management solutions e.g., for the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) e.g., the network controlled time-domain enhanced Inter-Cell Interference Coordination (eICIC) and autonomous component carrier selection. On the other hand, these have limited flexibility and applicability to nomadic small cells and dense small cell deployments. Therefore, interference management schemes for future networks have to be more flexible and responsive to the variations in future wireless network environment where changes in the traffic and deployment are expected to occur more rapidly than today's networks.

What is more, social wireless networks, which are formed of groups of smart devices, are emerging e.g., Neighbor Awareness Networking (NAN) [13]. Wireless devices are expected to constantly interact with each other (e.g., direct device-to-device communications) and environment (e.g., sensors and tags). To respond the challenges coming along with the increasing density of nodes and alternating connectivity options, user autonomous algorithms become essential. Therefore, future smart devices are designed to learn and decide how to manage the connectivity with the assistance of the context information. Context information could be simply the upcoming service profile or battery status of a device. Furthermore, it could be more detailed data obtained through serving base station, cloud servers, wireless devices around the user and built-in sensors. For instance, context information on social networking can be utilized to decrease the signaling overhead in the network since UEs would be able to facilitate faster initialization of direct Device-to-Device (D2D) communications and local multicast group forming. In addition to user autonomous algorithms, context information can assist the network to optimize the mobility and traffic management policies and local handover parameters or to decrease energy-consumption in base stations (e.g., switching of cells or base station radios).

All in all, future small cell networks and next generation smart devices will be able to provide the optimal wireless connectivity with a lower power consumption (and minimal interference thereof) adapting rapidly to the varying needs of devices and radio access network.

IV. Increased available spectrum and more agile spectrum use

The forecasted increase of wireless traffic per area by a factor of 1000 by 2020 [1-3] sets challenging goals for research and development. There is not a single factor that can address this challenge, but rather a combination of factors. For instance, a contribution of 10 times more spectrum could be good enough, if in addition the networks would be 10 times denser (i.e. more base stations in the network with smaller inter-site distance), and 10 times improvement in efficiency would be achieved via other technical enablers. The objective of 10 times more spectrum includes getting access to new spectrum and methods to use the currently available spectrum more efficiently. So technologies with increased spectral efficiency, as well as novel heterogeneous network deployments with distributed cooperation of devices, have to be developed.

Research on spectrum has put a lot of weight or even hyped on the secondary use of the UHF band and TV white spaces, using mainly geo-location database techniques as the basic way of spectrum sharing. This is a good start which should be extended to opportunistic ways of spectrum sharing to any commercially viable segments of the whole spectrum, under the vision that any portion of spectrum that is not being used at a certain time and location can be used.

Traditionally mobile communication services use spectral resources below 6 GHz and this part of the spectrum is becoming quite crowded, therefore towards future systems it is a valid long term research question to explore other opportunities. New spectrum could also be available from significantly higher frequencies than before, like around 60 GHz. Naturally the propagation characteristics of such spectrum would limit to directed point to point links or rather small cells in case of omnidirectional connectivity.

Currently available spectrum could be more efficiently used via different methods of spectrum sharing. For example ETSI RRS has started standardization of Licensed Shared Access (LSA), to allow authorization of the usage of some temporarily unused spectrum with the quality of primary licensed spectrum. Difference to exclusively licensed spectrum here is the potential need to evacuate the spectrum in case the primary owner needs it. However relatively stable conditions would lower the threshold for using the spectrum and investing in infrastructure enabling the use.

Unlicensed spectrum could also be more efficiently used with novel methods for coexistence. One example of this is LTE on unlicensed band with additional enablers for coexistence, like listen before talk [4].

V. Challenges in Channel Modeling

New radio propagation models are needed to evaluate the performance of future radio access technologies. A new geometry-based stochastic channel model is developed by METIS project to meet the needs of future communications system. The novel features of the channel model include three-dimensional modeling, support for wider range of frequencies and support for direct communication between two mobile terminals. Radio propagation measurements are needed to better understand the behavior of the channel with respect to these features.

To increase capacity, three-dimensional structure of the channel is going to be utilized more in the future. This can mean e.g. separating the cellular users not only in horizontal but also in vertical domain with a 2 or even 3 dimensional array. Understanding of 3D characteristics of the channel is required to test and optimize the performance of such techniques.

Current models are typically designed for frequencies below 6GHz. In the future, when more bandwidth is required, also higher frequencies are taken into use. At higher frequencies, path loss is typically higher and thus the range is smaller. New models are required to adequately describe propagation characteristics at carrier frequencies up to 60GHz, and even beyond.

D2D communication between two mobile terminals will allow new use cases for devices. This peer-to-peer channel has different characteristics compared to the conventional cellular channels of contemporary propagation models. One difference is the height of the terminal: in current models one end of the link is typically situated higher than the other end of the link. In D2D such asymmetry doesn’t exist. This has an impact on at least path loss and shadowing, but probably also distributions of small scale characteristics of the channel.

Another difference between cellular and D2D models is that in D2D both ends of the link can be moving, whereas in cellular models the base station is static. This has an impact on the temporal evolution of the channel.

VI. Advanced Interference Cancellation Technologies

HetNet deployment, with a lower-power small cell layer complementing the macro cell coverage area, is currently seen as a key enabler technique to improve the network capacity through cell-splitting and traffic offloading. On the other hand, compared to homogeneous network deployments, HetNets unavoidably result in increasingly challenging interference-limited operation requirements from a UE’s perspective due to more severe inter-cell interference (ICI) characteristics as a result of the overlapping footprints of the different layers (in many scenarios).

Recently, research has been conducted in 3GPP, on multiple fronts, to tackle the issue of ICI in LTE cellular networks. More specifically, one study investigated UE’s ability to cope with ICI, without assistance from the network side, by means of advanced interference rejection combining (IRC) receiver structures, exploiting the estimated spatial correlation structure of the interference [8, 9]. In another study on eICIC [10], techniques based on network-side coordination of transmit resources (jointly in power, frequency and time domains) were investigated and developed aiming to control and mitigate the cell-edge interference from neighbor cells. In this context, the role of a UE operation was limited to participating in resource-restricted channel state information or measurement reporting to support the coordination process. Yet another 3GPP study has focused more specifically on HetNet scenarios, such as the macro-pico deployment with UEs operating in the cell range expansion mode, which are known to impose harsh ICI conditions. In that context (in 3GPP referred to as Rel-11 Non-CA feICIC) [11, 12], techniques have been developed, which complement time domain resource partition (based on so-called almost blank subframes) between the aggressor and victim cell layers with explicit non-linear interference cancelling receiver processing.

It is of great interest to study the potential of further improving UE’s ability to suppress/cancel ICI as well as intra-cell interference with the aim to improve the cell-edge and cell-average throughputs of the future networks. In particular, it is considered important to investigate and analyze feasibility and performance of novel interference mitigation techniques which increase the role of the interference cancelling/suppressing-capable UE receivers in the interference-limited network design provided their operation is supported by assistance from the network side. More specifically, assuming the network side (eNBs/access points in the coordination/collaboration set) could provide UEs with appropriate side information on the interference, regarding to, e.g., transmission scheme, precoder selections, reference signal ports, modulation and coding schemes, resource allocations etc., which would lead to potential improvements in UE receiver’s ability to estimate and mitigate intra-cell inter-user interference and/or inter-cell interference and consequently improve its effective post-IC/IS SINR, should be investigated. A careful performance evaluation and analysis of potential receiver types and their associated IC/IS schemes for mitigating different interference sources are required to achieve interference management solutions that provide balanced complexity (considering both UE and network sides) vs performance trade-offs.

VII. Very Large Antenna Arrays

A physical layer improvement that has sparked recent interest is the utilization of very large antenna arrays. Moving toward higher carrier frequencies may make this development possible without increasing the physical sizes of the devices. From a theoretical standpoint, it has been shown that the large antenna arrays may result in a paradigm shift in the way Multiple-Input Multiple-Output (MIMO) systems operate [5, 6]. In the limit of increasing the transmit antennas to infinity, the transmit power may be reduced arbitrarily, and intercell interference may be mitigated by utilizing simple matched filter spatial processing. These results apply for a TDD system that can utilize reciprocity in the channel estimation. The extent to which intercell interference is mitigated is only limited by the so-called pilot contamination that arises due to correlation between different users' pilot sequences.

In this respect, the most interesting scenario is formed by base stations with large 2 or 3 dimensional arrays, while the terminals could be still equipped with a small number of antennas. Particularly, the terminals are more restricted in terms cost, energy consumption, and size (maximum number of antennas with low mutual correlation and coupling). Having the base stations equipped with a large array facilitates steering energy toward desired receiver, and also away from the interfered receivers. The opportunities for multiuser MIMO are greatly increased. However, the scenario at the same time poses challenges in terms of the so called flashlight effect. A given receiver may observe very high fluctuation of received interference power. This fluctuation, if not taken into account and possibly managed, may reduce the system level performance gains available from user specific precoding [7]. It is foreseen that the impact from the interference fluctuation may be emphasized when the number of transmit antennas is increased and when the data traffic is more bursty. Another practical challenge arises from the fact that the described system may be only operated reasonably by relying on channel reciprocity for obtaining the spatial CSI. However, the reciprocity does not hold for the interference. Hence, the base station must still rely on channel quality information feedback for determining the proper modulation and coding parameters for the downlink communication. This together with the flash light effect makes the link adaptation and scheduling very challenging. System level simulations are needed to shed light on these aspects of very large antenna arrays, which may limit the gains achievable in practice.

VIII. Conclusion

This paper addresses challenges when designing wireless systems towards the communication needs of society in 2020. End-users will expect an excellent user experience while using mobile services as an integrated part of their lives very much beyond today's usage of mobile services. This results in increased capacity needs, and the need to support a wide range of requirements in a very versatile and scalable manner.

This paper points out several important technologies that will enable future systems to meet these requirements. These technical components include:

- support for dense small cells,
- increased and more flexibly available spectrum,
- advanced interference cancellation techniques, and
- very large antenna arrays.

Wireless systems of the future should improve the performance of networks under very demanding cost and power consumption constraints.

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