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HIGH PERFORMANCE MICROELECTRONICS

# Wireless 100 Gbps And Beyond

ARCHITECTURES, APPROACHES AND FINDINGS OF  
GERMAN RESEARCH FOUNDATION (DFG)  
PRIORITY PROGRAMME SPP1655

*Rolf Kraemer and Stefan Scholz (Editor)*

IHP GmbH  
Im Technologiepark 25  
15236 Frankfurt (Oder)  
GERMANY  
[www.ihp-microelectronics.com](http://www.ihp-microelectronics.com)

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## *Preface*

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“Wireless communication” is one of the fastest growing technologies driving the development of microelectronics even fast than the processor technology. This is due to the high practical use of wireless systems and its widespread availability worldwide. Thirty years ago, the introduction of GSM fundamentally changed the communication behavior of people. All of a sudden communication potential was ubiquitous available. Everybody was able to communicate at any time everywhere with almost anybody worldwide. This possibility changed the world.

Today we cannot even think to live without wireless communication. Since the early 1990s it developed rapidly not only changing telephony but especially also data exchange in all areas of the society. Today, we rely on the continuous availability of broadband communication with high data rates good quality of service and short latency. 5G, the new cellular standard is an example of the rapid development making data-rates of Gbps with latencies of  $< 1$  ms available.

And the development continues! In the near future we will be able to communicate with even much higher data rates such that the amount of information continuously at our hand will be huge. In the area of wireless LANs even higher data-rates are available today reaching up to and beyond 10 Gbps. IEEE started working groups on 100 Gbps technologies recently expecting to introduce standards in the coming years.

In 2012 a group of researchers proposed a basic research initiative to the German Research Foundation (DFG) as a special priority project (SPP) with the name: “Wireless 100 Gbps and beyond”. The main goal of this initiative was the investigation of architectures, technologies and methods to go well beyond the state of the art.

The target of 100 Gbps was set far away from the (at that time) achievable 1 Gbps such that it was not possible to achieve promising results just by tuning some parameters. We wanted to find breakthrough solutions.

When we started the work on the proposal we discussed the challenges to be addressed in order to advancing the wireless communication speed significantly.

Having the fundamental Shannon boundary in mind we discussed how to achieve the 100Gbps speed. Basically we can improve several basic parameters:

- Increase the bandwidth of the transmission channel
- Increase the bandwidth efficiency
- Increase the SNR
- Increase the number of independent channels

The increase of bandwidth leads to the increase of the center frequency of the transmission since the frequency spectrum below 10 GHz is completely used. So we need to consider going to mm-wave systems like 60 GHz or even beyond. Some projects addressed systems at 240 GHz center frequency with a bandwidth of 25 GHz.

Increasing the bandwidth efficiency allows to use lower bandwidth and also lower center frequencies. This is an advantage since free space loss increases with the square of the frequency. Therefore we have better SNR available at the receivers. However, increasing the bandwidth efficiency increases the complexity of the baseband signal processing significantly. This in fact increases the power dissipation. If we intend to integrate a 100 Gbps system into a mobile device we should restrict the power dissipation to  $< 1$  W. This, however will restrict the energy budget per transmitted bit to  $< 1$  pW which is really challenging. With complex signal processing it is even more difficult to stay within these limits.

The increase of SNR is possible by increasing the signal power and reducing the noise. Most of the noise is caused by thermal processes such that only cooling the devices will reduce the noise level. This however will increase the energy budget significantly. Increasing the signal power is limited on the one hand by the restricted power budget and on the other hand side by the linearity of the used transmission components like power amplifiers, low noise amplifiers and also mixers.

The increase of the independent channels will allow to reach beyond the Shannon limit. However, we need to have transmitter- and receiver-systems per channel and this will also require significant power. However, MIMO systems are quite promising since they allow the combination of the merits of several channels.

As a summary: All possible approaches have pros and cons to be considered. At the time of proposing the SPP1655 we did not prefer any approach but allowed the researchers to propose their approaches based on their own experience. Interestingly more than one approach was successful.

Beyond the aforementioned challenges data converters seemed to be restricting devices. In 2012 a 10 GS/s ADC with 8 bit resolution consumed more than 10 W. This alone is more than the total anticipated power budget of the wireless system. Thus, we also considered architectures without data converters or with data converters with much lower resolution and sampling rate. The idea of “analog signal processing” or hybrid signal processing was very attractive. However, analog approaches suffer from different effect due to temperature, ageing, parameter spread etc. Thus another trade-off was to be considered between the advantages of digital processing and the disadvantages of power hungry data converters.

Finally, we also considered the challenge of protocol processing. With processor clock speeds of 3 GHz and a word-size of 64 bit we can process approximately 180 Gbps. But with only a single processor cycle we cannot realize complex protocol designs. Thus, we addressed the ideas of multiple parallel paths to be independently processed by several processors. A new form of protocol processor was necessary to allow the use of processor resources in a flexible way processing several parallel data stream concurrently.

The proposal, addressing all these challenges was accepted by DFG as SPP1655 and supported with almost 12 Mio. € for a duration of 2 times 3 years. Beyond the technical success, the project resulted in more than 40 PhD qualifications, several master and bachelor theses and more than 240 international publications.

This book summarizes the results of the research work achieved by the individual projects. We really succeeded in demonstrating 100 Gbps systems. We were able to advance the state of the art significantly in areas like antenna design, radio-frontend design, millimeter-wave technologies, advanced MIMO systems, baseband architectures and design, channel coding and also protocol design. The 12 projects which formed the SPP1655 are outlined in the following 11 chapters of the book.

We would like to thank all authors for their contributions! We also want to thank the DFG for the support allowing this research work to be conducted!

Prof. Dr.-Ing. Rolf Kraemer



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