ULTRA HIGH SPEED WIRELESS COMMUNICATION 
IN THE 250 - 300 GHz BAND

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Extended Abstract

Wireless communication is developing very rapidly both in speed and quality. Several new standards are emerging every year and try to find its place in new application domains. The work presented here addresses currently not reachable speeds in the range of 100 Gb/s and more at frequency bands of approximately 250 GHz. It is highly explorative and should indicate current road-blocks and suggest, how to remove some of them. We consider the project as a success if we come close to our original goals and if we succeeded to show that such high speeds are feasible at the indicated frequency band.

The idea of this work came up in discussions with several colleagues like Prof. Robert Weigel from Erlangen and Prof. Gerhard Fettweis from Dresden. We discussed the limit of current wireless communication and tried to predict a future roadmap. In a recent publication [1] Prof. Fettweis published an indicative roadmap for mobile communication that assumes a link between the required communication speed and the development of new non volatile memories (NVM) like FLASH, MRAM etc. This development however behaves according to Moores law such that we will have NVMs of 10 - 40 GByte in mobile devices in the near future. In Figure 1 the roadmap according to the Fettweis paper is shown. As shown 100 Gb/s should appear on the market in less than 10 years. Unfortunately this roadmap predicts the future only based on requirements not based on technical capabilities. To meet the goal of the roadmap we need to make some assumptions about the technical specifications, about bandwidth, bandwidth efficiency, carrier frequency, modulation, medium access etc.

Figure 1: Roadmap for short range wireless communications (according to Fettweis)

This paper speculates on such assumptions and even more it tries to set some requirements for developments necessary to come close to the 100 Gb/s. It furthermore tries to discuss the requirements in terms of technical feasibility such that we can get some feeling in terms of realizations.
Let's first make some assumptions about bandwidth and bandwidth efficiency and deduce a potential carrier frequency. Today modern WLAN systems using OFDM based basebands combined with MIMO use typically 20 - 40 MHz bandwidth and can reach up to 600 Mb/s communication speed as indicated in IEEE802.11n. This results in bandwidth efficiency of up to 15 b/sHz. Looking a little bit more closely to this figure you will find that the maximum can be reached only under optimal conditions in a very short range using a frequency band at 2.4 GHz or 5 GHz. In this band the propagation conditions for electromagnetic waves are quite good and the challenges with respect to RF-designs are quite manageable. New discussions in the IEEE802.15.3c already try to go beyond the 1 Gb/s and achieve 2 - 6 Gb/s by using the 60 GHz Band [2,5,6]. Currently the bandwidth for this speed is 2 GHz which results in a bandwidth efficiency of less than 1. This is due to the different propagation behaviour at the 60 GHz band as well as used approaches. If we used all possible optimizations with multi antennas a bandwidth efficiency of 6 - 8 could be achieved. This, however shows that bandwidth efficiency is inversely related with the carrier frequency, i.e. the higher the chosen band the lower the achievable efficiency. If we want to come to 100 Gb/s and have to find a band with enough bandwidth at a reasonable bandwidth efficiency. To do this we looked at the frequency allocation map and assumed an achievable bandwidth efficiency of 4 at frequencies above 100 GHz (which have not been shown until now). In that case we need 25 GHz bandwidth and the first band that provides such a wide spectrum is at 250 GHz. From 250 - 300 GHz we have 50 GHz free which fulfills the requirements. Above 300 GHz currently no regulations are available. Transceivers at this frequency have not been reported in Si based technologies until now. This is due to the available transistors that have maximal cut-off frequencies of approximately 400 GHz in advanced SiGe technologies.

So let's have a look to Si based transistors needed to design a Transceiver at above 250 GHz. In BCTM publications of 2004 and 2005 [3, 4] simulation results of SiGe HBT transistors are discussed that indicate a tentative cutoff frequency of above 1 THz. In figure 2 and 3 these simulation results are shown. They clearly indicate that higher Ge concentration results in higher $f_T$ and that smaller emitter sizes also lead to higher $f_T$ and $f_{\text{max}}$. Both are technologically highly risky.

<table>
<thead>
<tr>
<th>$w_E$ (nm)</th>
<th>120</th>
<th>100</th>
<th>80</th>
<th>60</th>
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<tr>
<td>$R_{B,\text{in}}$ (Ω-μm)</td>
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<td>$R_{B,\text{ex}}$ (Ω-μm)</td>
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<td>70.0</td>
<td>70.0</td>
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<tr>
<td>$C_{\text{CB}}$ (fF/μm)</td>
<td>1.14</td>
<td>1.10</td>
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<tr>
<td>$f_T$(GHz)</td>
<td>787</td>
<td>785</td>
<td>770</td>
<td>760</td>
</tr>
<tr>
<td>$f_{\text{max}}$(GHz)</td>
<td>745</td>
<td>871</td>
<td>968</td>
<td>1090</td>
</tr>
</tbody>
</table>

Figure 2: Relation between emitter size and $f_T/f_{\text{max}}$ [3]

From the point of view of the designer of a radio frontend we need to have enough available gain at the design frequency to build working transceivers. Normally approximately 50 % of the $f_T$ is a design point where experienced designers can still work. This results in minimum $f_T$ of approximately 500 GHz. According to the cited sources this should be a reachable target. Within the FP7 a new project have been started to investigate and develop transistors above 500 GHz. In so far we are optimistic that this problem will be solved in the coming years.
Several challenges will be connected to parasitic effects at 250 GHz. One major problem, however, will be connected to parasitic inductances and capacities. Due to the skin effect the resistive losses will increase such that VIAs will be difficult to realize.

If we look to the baseband challenges we again need to makes some assumptions. If we just take similar baseband approaches as today the DSP processing equivalent will come to approximately 500 GFLOPS. This is an extreme speed even for highly scaled CMOS at 45 nm. So we need to look at the baseband effect and have to develop new more adapted scheme for 100 Gb/s. A good candidate seems to be PSSS. Similar to CDMA access in PSSS several orthogonal codes are generated that can be transmitted conflict free over the medium. In PSSS several codes are generated per user such that the bandwidth efficiency can be increased. PSSS can be combined with other multi-carrier approaches like OFDM such that an optimized solution could be developed. Moreover PSSS promises a much easier baseband processor with at least 10 times less DSP operations which would bring us to 50 GFLOPS. This speed seems to be reasonable in approximately 10 years.

If we look at the MAC layer we also have to address several challenges. One of them is extreme data packet aggregation. Today the average payload of a data packet for a wireless communication system is between 1500 bits and some view kilobytes. The short packet size has been chosen due to the inherent high bit error rate. In extreme fast communication systems, however, the ration between the header and the payload becomes much more an issue. To have a real high throughput one has to aggregate several messages to avoid large header overhead. Therefore new methods for buffer control and flow control have to be realized. Moreover the high speed requires also very short reaction time to avoid reduced throughput. Today the generation of an ACK messages requires approximately 5 µs. In 100 Gb/s systems 5 µs equals 500 kb of data. A reduction to approximately 0.5 µs seems to be necessary.

As indicated throughout this contribution 100 Gb/s are not feasible today. We are searching for solutions, conventional and unconventional to achieve our goal. In any case we need to remove several basic roadblocks before we can consider ourselves to be successful.
[3] Yun Shi and Guofu Niu; “2-D Analysis of Device Parasitics for 800/1000 GHz \( f_t/f_{max} \) SiGe HBT”; Alabama Microelectronics Science and Technology Center Electrical and Computer Engineering Department, Auburn University, Auburn, AL 36849, USA; BCTM 2005
[4] Yun Shi and Guofu Niu; “Vertical Profile Design and Transit Time Analysis of Nano-Scale SiGe HBTs for Terahertz \( f_t \)”; Alabama Microelectronics Science and Technology Center Electrical and Computer Engineering Department, Auburn University, Auburn, AL 36849, USA; IEEE BCTM 11.2