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Scientific Report

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| Nationality | Pakistani |
| Name of the <i>Host Organisation</i> | Fraunhofer Heinrich Hertz Institute, Berlin, Germany |
| First Name / family name of the <i>Scientific Coordinator</i> | Thomas Haustein |
| Period of the fellowship | 01/06/2011 to 31/05/2012 |



I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

During my stay at Fraunhofer Heinrich Hertz Institute, I have been working with a team of fellow researchers on the topic of green radio communication. The group of broadband wireless communications and networks is headed by Dr. Thomas Haustein. The research was completed in connection with the project Communicate Green.

Traditionally, increase in data rate has been the main focus of research because of ever increasing traffic demands and limited available bandwidth. However, the focus has shifted to energy efficient communication in recent times due to high energy costs of operating a network. A big proportion of base station sites installed in Africa and Asia are off-grid where diesel consumption enhances the cost sharply. It is predicted that the cost of energy will double by 2020. In a mobile network, base stations alone are responsible for 80 percent of network's power consumption. Therefore, a lot of emphasis has been put on the optimized design of base stations and exploring renewable energy sources for off-grid sites.

High energy consumption in mobile networks has environmental effects as well. The whole information and communication technology sector is estimated to be responsible for about 2 percent of global CO₂ emissions and the corresponding figure for mobile networks is 0.4 percent. These economic and ecological factors demand for serious measures to investigate the possibility of energy efficient communication.

In our work, we consider a network scenario where long term average traffic requirements vary considerably over the time horizon, e.g., day and midnight situation in an industrial area. The network is configured to provide quality of experience at full load situations usually. However, when a network is not fully loaded, network resources are under-utilized and energy efficiency of the network can be improved by reconfiguring some of the parameters of the network. In a lightly loaded system, bandwidth is available and can be exploited to reduce the energy consumption by using low order modulation and coding schemes. We use the bandwidth expansion scheme for the lightly loaded system and evaluate the gain using system level simulations for the Long Term Evolution (LTE) system.

We propose trading bandwidth with power to make the network more energy efficient. Although the idea is well known in literature, our main contribution is to quantify the limits of bandwidth expansion factor and possible energy gains with LTE system level simulations for the interference model and the scenarios applicable in practical networks. We evaluate the adverse effects of bandwidth expansion on the neighboring cells. We conclude that base station offset power and increased energy expenditure in the neighboring cells limit the use of bandwidth expansion schemes. However, at moderate low loads, bandwidth expansion schemes are still a better option than the sleeping mode techniques due to small implementation complexity.

In another area of research, we worked on exploiting the delay and loss tolerance characteristics of the application to achieve energy efficiency in a multiuser system. We developed and analysed packet scheduling schemes which use the radio resources energy efficiently and fulfil the quality of service requirements for the applications in terms of maximum tolerable delay and packet loss rate.



II – PUBLICATION(S) DURING YOUR FELLOWSHIP

1. **M. Majid Butt, Benjamin Schubert, Martin Kurras, Kai Börner, Thomas Haustein and Lars Thiele**, “On the Energy-Bandwidth Trade-off in Green Wireless Networks: System Level Results”, submitted for publication to *Smart and Green Communications & Networks workshop at IEEE international Conference on Communications in China (ICCC)*.
2. **M. Majid Butt**, “Deadline Delay Constrained Multiuser Multicell Systems: Energy Efficient Scheduling” accepted for publication in *IEEE International Workshop on Signal Processing advances in Wireless Communications (SPAWC)*, Cesme, Turkey, June, 2012.
3. **M. Majid Butt**, “Energy-Performance Trade-offs in Multiuser Scheduling: Large System Analysis” accepted for publication in *IEEE Wireless Communication Letters*.

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

1. I will attend *IEEE International Workshop on Signal Processing advances in Wireless Communications (SPAWC)* in Cesme, Turkey in June, 2012 and present my accepted paper.
2. Attended a seminar at Technical university Berlin entitled “Green Cellular Networks: A Survey, Some Research Issues and Challenges” by Prof. Vijay Bhargava from University of British Columbia, Vancouver.
3. Attended a seminar at Technical university Berlin entitled “10 Years of Multiuser MIMO” by Prof. Giuseppe Caire from University of Southern California, California.

IV – RESEARCH EXCHANGE PROGRAMME (REP)

For my first external research visit, I chose University of Luxembourg. I visited Prof. Bjorn Ottersten at Interdisciplinary Center for Security, Reliability and Trust. I gave a seminar to the group about my research activities. I got an opportunity to meet most of the researchers and PhD students working in the area of signal processing and wireless communication and discuss their research activities. We talked about the possibilities of collaboration in the common areas of research.

For my second research visit, I visited Prof. Ralf Müller at the signal processing group, Norwegian University of Science & Technology, Trondheim, Norway. I was already collaborating with the group from some time. We shared ideas on the topics of multiuser scheduling and large system analysis; and worked on the completion of an on-going research article.