

**Real Time MIMO and Cooperative MIMO Systems Testbed for latest Wireless
Broadband Systems**

B. Project Summary:

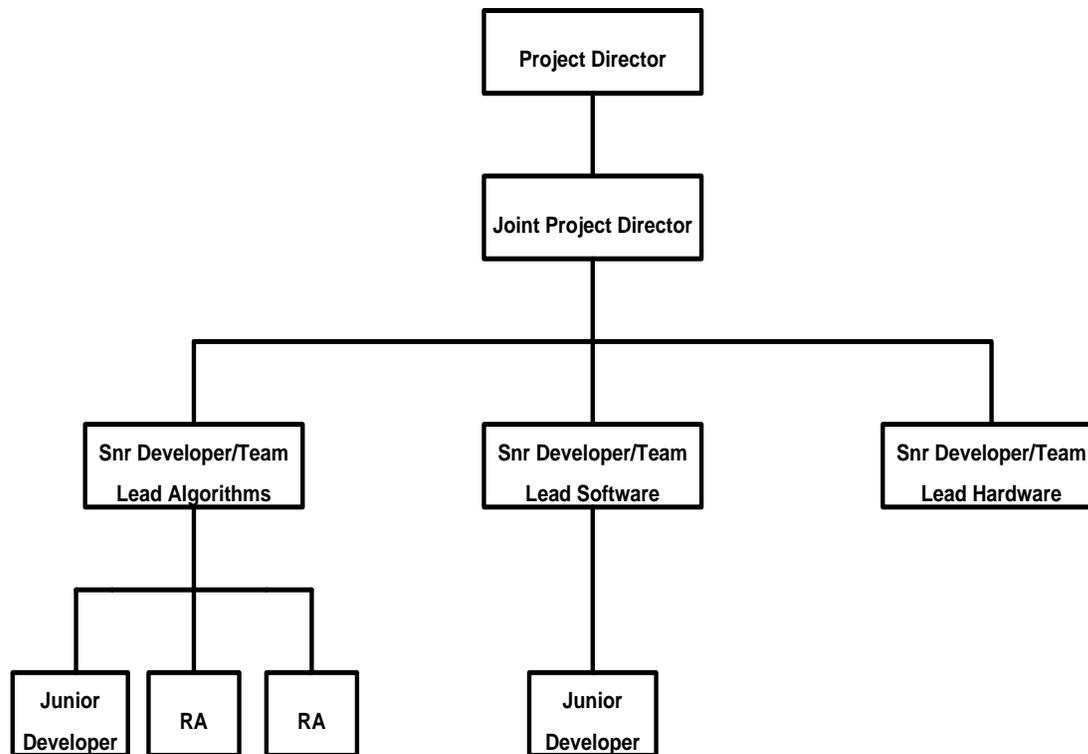
1. Project Objectives:

- Research on the MIMO detection algorithms and Cooperative-MIMO (C-MIMO) algorithms including development of new algorithms and implementation in Matlab.
- Development of a flexible, real-time MIMO testbed for research and rapid prototyping of wireless systems” with following capabilities.
- **Real-time Operation:** Testbed should enable algorithm and protocol testing under real-world conditions. Here, simulation only solution is not acceptable as it demands real-time implementation on hardware platform.
- **Flexibility:** Tested should be flexible enough to support wide range of wireless protocols. Software defined radio based approach is the only option as it allows the same hardware to be used for multiple standards by simply changing/modifying the software.
- **Rapid Prototyping:** This was another key requirement that testbed should allow quick and easy experimentation. The solution is to do programming in higher level languages C/C++/Python rather than lower level languages like Verilog RTL that require special expertise.
- **Reasonable Throughput:** Testbed should be able to process a few MHz of bandwidth. A combination of software (host processor based) and hardware (FPGA based) implementation is required.
- **Cross Layer Optimization:** It should support both PHY and MAC layers for cross layer optimizations.

Results: Successfully achieved the project objectives by implementing a complete real-time MIMO testbed. We have provided a flexible SDR framework that researchers and professional can use for development, testing, rapid prototyping and cross layer optimization of MIMO OFDM based systems.

Can transmit up to 2 Mbps of data over the wireless using a 2x2 MIMO system. Furthermore new algorithms for MIMO detection were developed and performance was compared with the existing algorithms. Research papers were published in the reputed international conferences.

- 2. Research Approach:** Started with a comprehensive study of all MIMO-OFDM standards like WLAN, WiMax and LTE and identified the basic structure that can support all these systems. After finalizing requirement specifications we started the implementation work. Initially all the development was done in Matlab and results were compared with the published results. Then we started implementing algorithms on GNU Radio for real-time implementation. After testing real-time implementation, we moved a compute intensive part of inner receiver algorithm to FPGA.
- 3. Team Structure:** Team was combination of PhDs, researchers doing masters/Phd and professionals with rich industry experience. This diversity in our team allowed us to focus on theory as well real-time implementation. PhD researchers contributed towards the algorithm development especially MIMO detection algorithms in Matlab. Industry professionals implemented these algorithms in real-time on a GNU Radio Platform. Team structure is shown below.



C. Objectives and achievements

■ Original Project Objectives

Research Objectives:

1. To research advanced techniques for MIMO symbol detection. Analysis of Energy efficient C-MIMO techniques.
2. Implement efficient MIMO detection and energy efficient C-MIMO algorithms.
3. To suggest the hardware solution for detection in future communication systems.
4. SDR based real-time testbed development for MIMO OFDM system design, development and cross layer optimizations.
5. Computation intensive algorithms of should be implemented in FPGA while remaining blocks will be implemented in GNU Radio framework.

Other Objectives:

1. To provide an experimental/training facility for students/researchers in the field of wireless communication

■ Objectives Achieved

All of stated objectives are achieved.

1. Did extensive research on MIMO detection and developed our custom MIMO and C-MIMO Algorithms. It has resulted into new MIMO detection algorithms.
2. These algorithms are implemented in Matlab and results were published.
3. A complete hardware solution was suggested for development of MIMO systems
4. A complete real-time testbed has been developed for student/researchers for the development, testing, rapid prototyping and cross layer optimization of wireless systems and protocols.
5. Computation intensive algorithms are implemented on FPGA

D. Technology Transfer/Commercialization Approach

GNU Radio, an open source SDR framework, has been used in this project We are planning to make its software framework available to the open source GNU Radio community. Furthermore commercialization can be envisioned in the following areas:

Telecommunication/Wireless industry:

- Testbed can provide a quick start for prototyping of Customer Premises Equipment (CPE) for WiMAX and User Equipment (UE) for LTE.
- Network analyzers and scanners for WiMAX and LTE Networks.

University/Educational Labs

- Can be used as a lab equipment for undergraduate and graduate labs to enable real-time communication system design.
- Organizations/Research groups working on MIMO-OFDM systems can use the testbed to quickly experiment and test their algorithms in real-time environment.

It is important to note that these commercialization aspects were not there in the initial project scope but it became possible when the project scope was revised.

E. Benefits of the Project

■ Outputs of the project and potential beneficiaries

A range of MIMO detection algorithms has been implemented, including new algorithms of MIMO and C-MIMO. Research community and students are direct beneficiaries of this effort.

1. A real-time testbed has been developed that provides a platform for development and rapid prototyping of MIMO-OFDM based systems such as WLAN, WiMaX and LTE. Telecom industry and researchers are direct beneficiaries of this output.
2. Testbed is capable of transmitting rate up to 2 Mbps which is sufficient to demonstrate the working of different user applications. This real time real environment demonstration will help to convince industry to invest for the development of new tools and products.
3. Valuable human resource has been groomed in this project.
 - a. Two researchers have completed their PhDs during this project.
 - b. Three researchers got funding abroad and now they are pursuing PhDs in the field of wireless communications.
 - c. Two PhDs got offers from abroad and they are serving as senior research fellows on commercial projects in Australia and Saudi Arabia.
 - d. A number of undergraduate students completed their final year projects.
4. Three research papers were published in reputed international conferences.

This project was one of the early adapters of the GNU Radio framework which is used by most of the prestigious wireless research groups around the world. We have provided coaching to a number of undergrad and post grad students of different local universities.

■ **Organizational Outcomes**

1. A team of researchers has been developed with hands on experience of the development of MIMO-OFDM testbed. But when the funding stopped in 2009 for almost two years it became impossible to keep the team intact.
2. Nevertheless the key human resources that developed the testbed stayed with the project and got the valuable experience of working on MIMO OFDM systems.
3. This is the first ever real-time MIMO testbed developed in Pakistan. Organization and project team received widespread recognition for their efforts.

■ **National Impacts**

1. As it is mentioned earlier that it is the first ever real-time MIMO testbed developed in Pakistan. It can be extended to the products for international telecom market like Network Scanners for WiMax, Small Cells for 3G/LTE, CPE development for WiMax etc.

Human resource developed is fully capable of carrying out the R&D projects of telecom market catering to national and international needs.

F. Assessment of Project Structure

■ **Project Team**

Performance of the team was good as we had an excellent combination of experienced resources from industry and academia. Team structure has been provided in section B (Project Summary) of this document.

There were no significant departures of from the structure but few positions remained vacant because people left when funding stopped during the project. Budget saved from the salaries of these vacant positions was used to extend the project timeline because the scope of the work was increased during the project. There were few key resources who stayed with the project throughout and played critical role in its completion.

- Collaborated with the RF design team of Renzym Private Limited to propose new MIMO hardware design. Moreover their team helped in tweaking the existing USRP boards for better testing and integration.

G. Research Approach

Started with a comprehensive study of all MIMO-OFDM standards like WLAN, WiMax and LTE and identified the basic structure that can support all these systems. During this study we realized that testbed can be useful only if is implemented on SDR framework in higher level language so that researcher can easily implement and test their algorithms. Furthermore we also realized the need for cross layer optimization support so that protocol can be easily tested. This led us to the GNU radio framework which meets most of our requirements. We also identified the USRP hardware that could work with GNU Radio framework. Next step was to finalize requirement specifications.

This change of scope, software framework and hardware promoted an overall change in the direction of project. After deliberations with ICT R&D our suggestions had been accepted through a change request form.

Initially all the development was done in Matlab and results were compared with the published results. Then we started implementing algorithms on GNU Radio for real-time implementation. After testing real-time implementation, we moved the compute intensive part of inner receiver algorithm to FPGA. GNU radio based software framework capable of both MAC and PHY functionalities was a major change in the project scope but adoption of GNU radio helped making testbed more flexible and easy to use for the researchers.

H. Assessment of Project Schedule

The project has been extended beyond the schedule because of few reasons.

1. The scope of the project changed in the middle because initially envisioned FPGA based platform was not flexible enough for researchers to experiment and rapidly prototype systems. This change in scope required some system components to be moved from FPGA to PC. Furthermore the magnitude of the work was increased significantly which caused a delay in the overall completion.

I. Assessment of Project Costs

There were no departures from initial approved budget and project was completed with the same budget.

J. Additional Project Funding obtained(In case of involvement of other funding sources, please indicate the source and total funding provided)

Iqra university, the PI, provided a lot of support to this project. They provided space and other utilities (e.g. electricity, UPS, generators, telephone, internet etc.) at no cost. IT personals of the university were available to provide IT related support.

