Electromagnetically Shielded Real-time MANET Testbed

Anna Kaszuba, Radoslaw Checinski, Michal Kryk, Jerzy Lopatka, and Leszek Nowosielski
Faculty of Electronics, Military University of Technology,
Gen. S. Kaliskiego 2 Str., Warsaw 00-908, Poland

Abstract— Mobile ad-hoc networks (MANETs) are fast growing methods of efficient wireless communications in highly mobile environment. Such networks can be designed using software simulators, that allow users to design, test and analyze new solutions at a low cost. These tools enable also an analysis of network configuration and protocol used for optimizing radio resources and performing the best Quality of Service (throughput, delays, etc.). However the simulators cause approximations of results due to simplification of EM compatibility issues and propagation phenomena in the electromagnetic environment. Furthermore the most common simulators do not allow the simulation in a real time, that causes long simulation. This problem can be solved using real time test beds, containing SDR (Software Defined Radio) base solutions. The most popular device based on this technology is USRP (Universal Soft-ware Radio Peripheral), that is widely used by researchers to study various transmission protocols or create real-time applications like OpenBTS or MIMO links.

1. INTRODUCTION

Mobile wireless networks offer a wide set of wideband services in different environments, and they can be used as a cost-effective mechanism for supporting communication. To provide reliable communications such networks should contain mechanisms for link quality monitoring, adaptive routing and interference avoidance. Proper operation of such mechanisms needs distributed algorithms, enabling joint configuration of whole network, that require exchange al lot of control data, so their efficiency is one of the most critical parameters of the network, and it should be thoroughly designed and tested. The most researches in the mobile ad-hoc rely on computer simulation and there are many commercial and open source programs that help to build communication models. However, these models do not fully reflect radio propagation phenomena and other electromagnetic dependencies. From the other side, experiments performed in a real environment are expensive; require a large number of testers and work coordination over a large geographic area [1]. Even with careful choreography, such experiments are only marginally reproducible, making testing and debugging difficult. Therefore, to minimize time, costs and human resources, tests can be performed in laboratory-based wire testbed, using devices that emulate wireless channels [2].

This article describes a real-time testbed for MANET, where each radio node is represented by one USRP. Electromagnetic environment emulation is performed by RF switch matrix, providing attenuation of RF signals. The work presents also the software architecture of radio nodes including implemented physical layer based on OFDM (Orthogonal Frequency-Division Multi-plexing) modulation and MAC (Media Access Control) layer based on TDMA (Time Division Multiple Access) radio access. Next, control process of whole test bed and RF switch matrix is described. The obtained results show performance of the testbed.

2. HARDWARE ARCHITECTURE

The overall concept of the wired testbed for wireless MANET is shown in Figure 1.

The laboratory-based ad-hoc network model consists of: RF switch matrix, RF-shielded enclosures, source of interferences, monitoring devices, clock signals distribution box, user computers, control computer.

This MANET testbed can be used for tests of up to 8 nodes using static and dynamic scenarios. Radio situation can be monitored and recorded for further analysis, using wideband receiver connected also to RF-switch matrix.

Additionally, in order to simulate scenarios with external interfaces, the arbitrary generator can be used.

The unit that control all these elements is the control computer, that manages each device using the Ethernet interface and multi IO card.

The testbed contains also clock signals distribution box, which delivers reference signals (10 MHz and PPS) to all radios, to enable tests with ideal synchronisation.

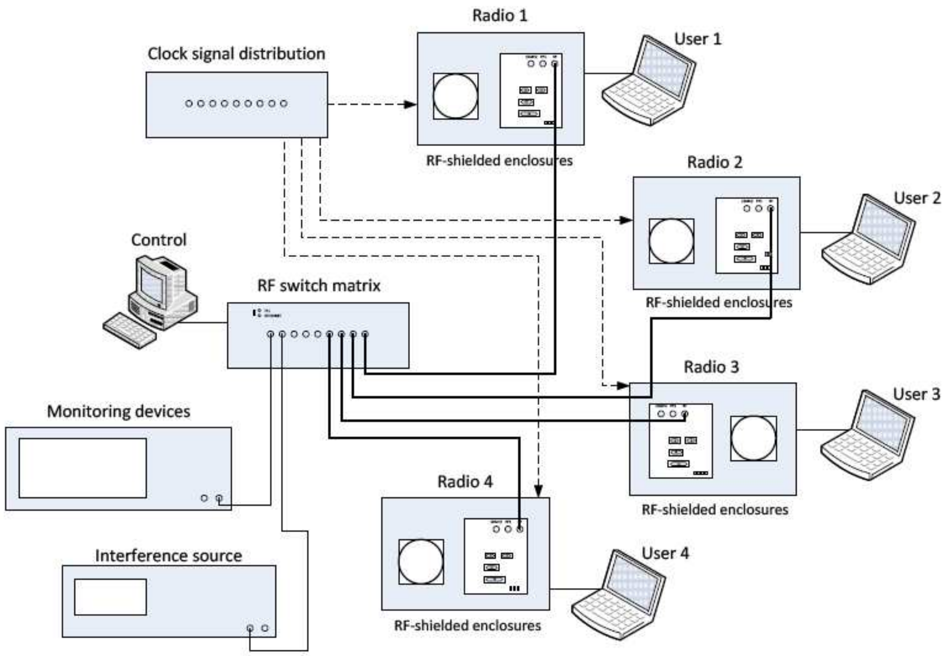

Figure 1: Concept of the MANET testbed.

2.1. RF Switch Matrix

This device emulates the telecommunication channels by adjusting attenuation in specific paths. It has the ability to connect up to 9 nodes with possible frequency range from 30 MHz to 3 GHz (Figure 2). The RF switch matrix consists of 36 programmable attenuators and 9 RF power divider/combiners [3].

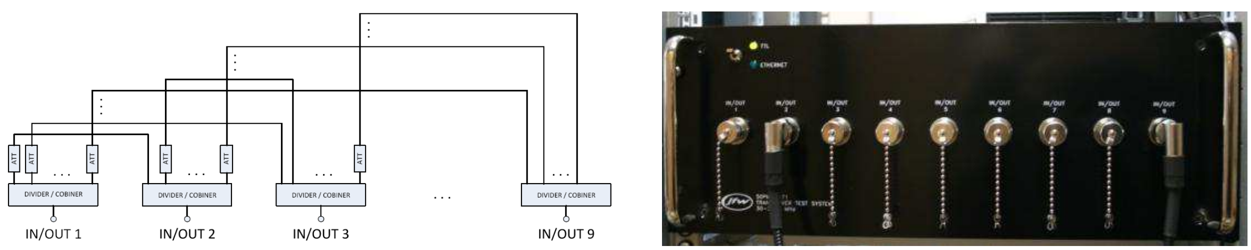

Figure 2: RF switch matrix.

This device can be controlled using LAN port or by parallel interface with electric signals in TTL standard. Attenuation switching time is up to 2 µs, therefore the RF switch matrix can create fast and slow fading, shadowing and nodes movements. The RF switch matrix can also set high attenuation between radios to block the communication, because the maximum attenuation between particular inputs/outputs is equal to 128 dB.

2.2. Radio Nodes

2.2.1. Universal Software Radio Peripheral

The USRP is a low cost software defined radio platform. It converts radio signal between baseband domain and high frequency domain and vice versa. In case of USRP Newtork Series the signal processing on baseband domain is performed by software at the host computer.

Architecture of USRP N210 consists of Ethernet interface controller, FPGA, dual ADC and DAC, RF daughter board [4]. It has the following external interfaces:

- Gigabit Ethernet — used for communication between host computer and the USRP,
- MIMO Expansion — to provide communication between two USRPs for MIMO systems,
- 1 PPS and 10 MHz inputs to synchronize the device.

2.2.2. RF-shielded Enclosures

During the MANET testbed operation, defined attenuation between nodes is required, whereas for USRP a significant crosstalk level of RF signal to the power circuits was observed [5].

Based on these results, RF-shielded enclosures (Figure 3) were designed as containers for tested RF devices that ensure an appropriate level of attenuation, to minimize radiated and conducted RF leakage between tested devices, and to provide separation of individual transceiver blocks.

The electromagnetic compatibility (EMC) measurements show that the level of attenuation for a single box does not exceed 50 dB for radiated disturbances in the frequency range from 80 MHz to 2.5 GHz. Characteristics of shielding efficiency, made in anechoic chamber are shown in (Figure 4).

Figure 3: RF-shielded enclosure.

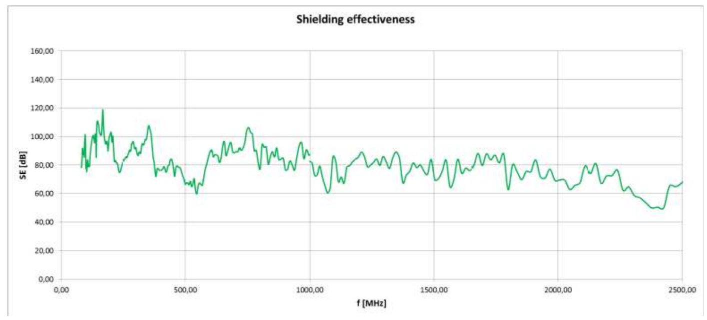

Figure 4: Shielding effectiveness in the range of 80 MHz to 2500 MHz.

3. SOFTWARE ARCHITECTURE OF RADIO NODE

This chapter presents short overview of software implementation of physical and Medium Access Control layer of each node used in the testbed.

3.1. PHY Layer

Physical layer bases on OFDM modulation. Figure 5 presents block diagram of transmitter and receiver part.

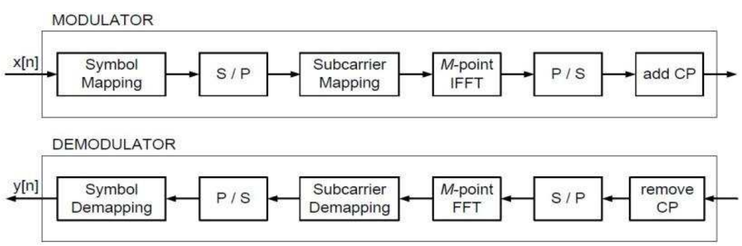

Figure 5: Block diagram of OFDM transmitter and receiver.

Physical layer is responsible for communication between host PC and the USRP, to enable transmission of modulated signals in proper time slots of TDMA frame. This feature is supported by UHD (USRP Hardware Driver) driver, that allows the user to send data with timestamp information, describing the time when the data should be transmitted. This time is synchronized with the USRP time. It can be set to time defined by user, or to the current UTC time, if the device is equipped with GPSDO sensor [6]. More information about frequency and time synchronization can be found in [7].

3.2. MAC Layer

MAC layer has been developed to perform hierarchical network organization, containing many clusters. Each cluster has 3 types of nodes: Cluster Heads, Regular nodes and Gateways. *Cluster Head* is the main node, which realizes radio resource allocation in the cluster. *Gateways* are responsible for communication between clusters and *Regular nodes* work as typical network users. MAC layer consists of three main parts: SAR (Segmentation and Reassembly) layer, queuing layer and TDMA scheduling.

MAC layer also provides other functionalities: dynamic cluster building [8], dynamic resource allocation, cluster graph colouring (determination of center frequencies for each cluster), neighbourhood discovery and maintenance.

4. TESTBED MANAGMENT

4.1. Control Application

The testbed contains devices controlled by one main computer with dedicated software. This software includes 2 components: for scenarios management and metrics display from all network nodes.

Scenario manager (Figure 6) enables loading scenarios from *xml* files, setting attenuations between all nodes, loading scenario map and setting all devices. Each radio node receives settings for physical, MAC and application layer. Data from attenuations data base are converted to set attenuator in RF switch matrix in specific time during scenario realization.

Result display component is presented on Figure 7. It contains the scenario map with marked position of each node and attenuations between all nodes. In the bottom right corner there is a tool for metrics display.

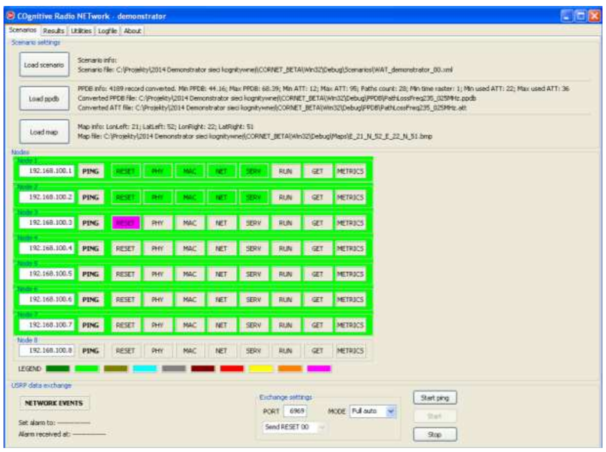

Figure 6: Scenario component view.

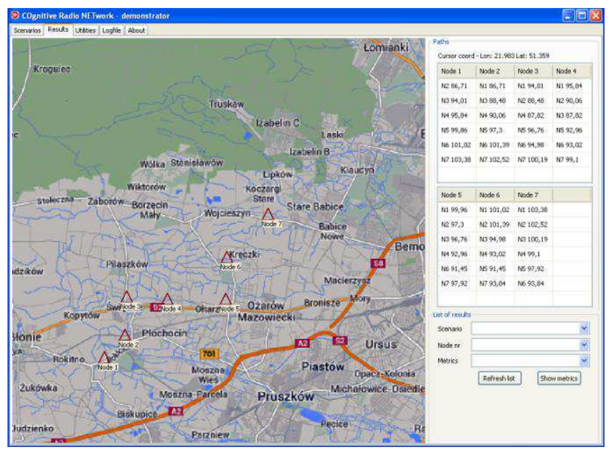

Figure 7: Results component view.

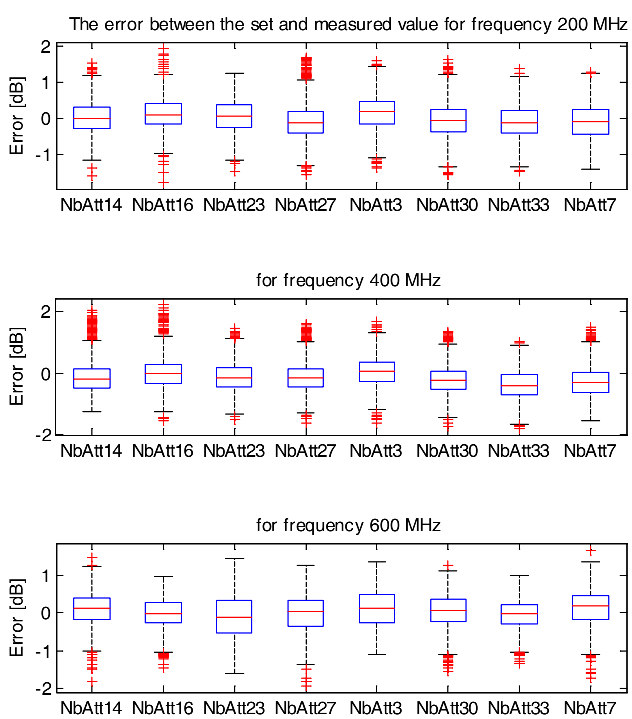

Figure 8: Accuracy of the RF switch matrix control.

5. TEST RESULTS

5.1. Accuracy of the RF Switch Matrix Control

To verify the accuracy of the RF switch matrix control, a one thousand different test sequences for nine input matrix have been performed. Nodes were placed at random positions in flat area and attenuations between them were calculated using free-space path loss model.

The results of the accuracy of the RF switch matrix control are shown in Figure 8.

Measurements are made for three different frequencies and for eight randomly selected paths in the RF switch matrix. The calculated error is the difference between the defined and measured attenuation.

5.2. Scenario Test Results

The testbed enables collection of metrics from physical and MAC layers, for example: RSSI, CFO, number of valid packets, data link layer throughput, MAC layer delay, MAC frame loss rate, MAC frame error rate. Figure 9 and Figure 10 present sample metrics collected during tests.

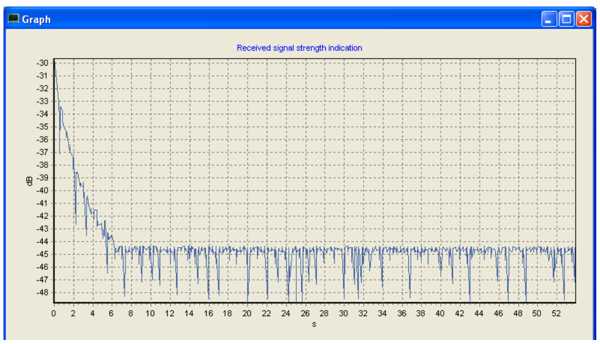

Figure 9: Received signal strength indication from node 1.

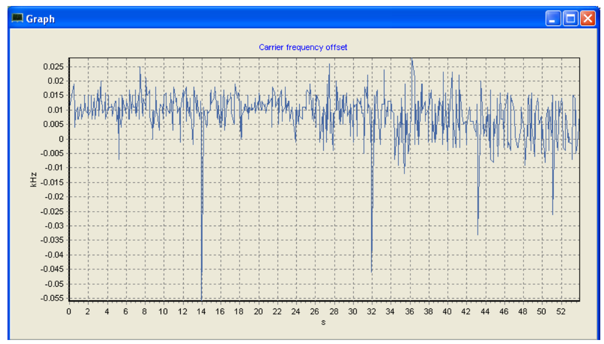

Figure 10: Carrier frequency offset for node 1.

6. SUMMARY

This article presents a laboratory testbed, using RF switch matrix for wire-based measurements of the MANET parameters, according to predefined scenario. The matrix inserts a programmable attenuation between selected RF nodes, to simulate a large-scale RF attenuation. All USRPs, creating MANET network are placed in RF shielded enclosures to minimize RF leakage. Collected metrics allow to estimate quality of links between RF nodes.

Achieved results show, that developed testbed is a reliable base for implementation of cognitive MANET with mechanisms for situation awareness and self-organization.

REFERENCES

1. Seastrom, J. and B. Walker, "Addressing scalability in a laboratory-based multihop wireless testbed," *Mobile Networks and Applications*, Vol. 15, No. 3, 435–445, 2010.
2. Clancy, T. C. and B. D. Walker, "MeshTest: Laboratory-based wireless testbed for large topologies," *3rd International Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities*, Lake Buena Vista, 2007.
3. JFW Industries, Available: http://www.jfwindustries.com/products/50PMA_033_Transceiver_Test_System_from_JFW_Industries-1290-137.html.
4. Research, E., "USRP N200/N210 networked series datasheet," 2012.
5. Kryk, M., A. Kaszuba, R. Chęciński, and K. Malon, "Laboratory-based Ad hoc network model," *SECON*, Warsaw, 2013.
6. Ettus Research, "GPSDO kit datasheet," 2012.
7. Research, E., "UHD — Synchronization application notes," 2012.
8. Bednarczyk, W. and P. Gajewski, "An enhanced algorithm for MANET clustering based on weighted parameters," *Universal Journal of Communications and Network*, Vol. 1, No. 3, 88–94, 2013.