Living Document - A Survey of Real-world and Emulation Testbeds for Mobile Ad hoc Networks

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Contents

1 Introduction

This document contains additional information to the conference paper [1], which surveys the state of the art testbeds for Mobile Ad Hoc Networks. Therefore, Section 2 will provide a closer look at the emulation approach, and gives valuable references to related work. In Section 3 we shortly repeat the categorization of the key aspects for testbeds and give a definition of testbed related terms. We introduce to the applied evaluation criterion in Section 4 which is followed by the evaluation. Section 6 provides a list of the evaluated testbeds with a short description and references to available software and publications.

Contributions regarding new or extended work in this area are very welcome. We would very much appreciate if you contact one of the authors for including you comments!

2 Background section

Today several methods exist to support MANET research. Generally, for analysis and comparison of different protocols and algorithms in MANETs, four techniques are applied: (1) analytical modeling, (2) network simulation, (3) real-world experiments and (4) network emulation. Substantial comparisons for (1),(2), and (3) are widely available in literature, i.e. [2]. Analytical modeling provides the highest, real-world measurement the lowest degree of abstraction. Simulation is based on abstract modeling of network layers, while real-world testbeds are based on existing implementations. Modeling techniques can differ significantly from each other, which leads to strong variations between simulation and real-world experiments, and furthermore to strong deviations between results of different network simulators [3]. Addressing MANET simulation, the highest inaccuracies are introduced by modeling the radio layer, where a detailed discussion can be found in [4]. Network emulation provides a hybrid approach, in which real layers are combined with simulation layers using an *emulation layer* for encapsulation. In general, emulations can be seen as an extension of a simulation system, where the *emulation layer* bridges real-world events to simulation events and vice versa. According to the method of integration of the bridging emulation layer into a simulation system, emulations can be classified as *horizontal* and *vertical* emulations [5]:

- In *horizontal emulations* a specific layer of the simulation protocol stack is replaced by a real implementation for that layer, e.g., taken from the operating system or provided by hardware. Thus, the emulation layer provides a proxy layer function for the functions of the real implementation.
- In *vertical emulations* the emulation software covers a group of consecutive layers of the protocol stack. Thus, the emulation layer provides a bridging

functionality between the functions of the real implementation stack and the simulation system stack.

Network emulation in the area of MANETs have been widely used to proof analytical models, verify simulation results, or preparing live experiments. In short network emulation increase the practical knowledge about real-world behavior and perform proof-of-concept demonstrations. In doing so, the emulation approach combines several valuable advantages:

- New applications can be tested and demonstrated in real-time, taking into account device specific limitations, e.g., processing power, buffer size, or interrupt delays. This allows testing and debugging of real protocol implementations, while providing a suitable development environment for research, education, and production.
- Similar to simulation, several emulation approaches allow the control of effects of the wireless layer adequately, and thus, to precisely rebuild certain network constellations. The fidelity of the emulation layer controls the precision of the repeatability.
- Additionally, emulation saves time and resources for protocol reimplementation, when switching from emulation to a real-world testbed. This reduces the number of software bugs as well as maintenance overhead, which occurs if simulation code has to be rewritten for a dedicated system.

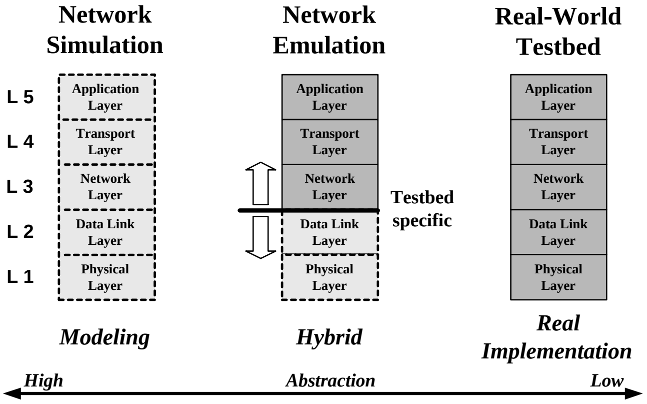

Figure 1: Layer abstraction model showing the stepwise evolution from simulation to real-world testbed scenarios using (vertical) emulation techniques.

As shown in Figure 1 we concentrate on the *vertical* emulation approach. Here, the underlying network protocol stack is replaced by an emulation layer, which provides the same service primitives as the original one, thus, conserving the transparency of the service access points for higher layer applications.

3 Categorization - Definition of testbed related terms

For the surveyed testbeds a categorization of technical key aspects was done [1]. The relation of this aspects is shown in Figure 2.The remaining part of the section defines the described aspects and adds definition of testbed related terms.

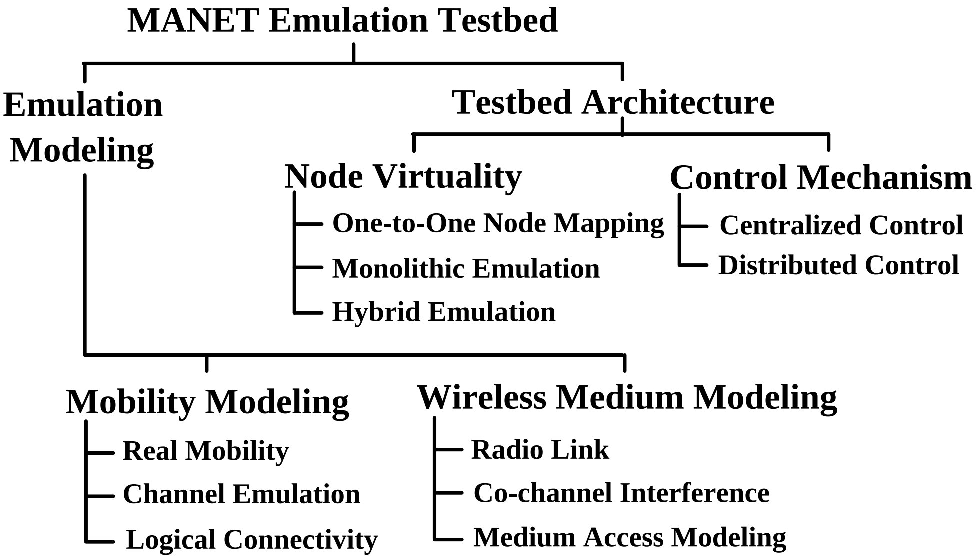

Figure 2: Categorization of technical aspects for the survey.

Real mobility: As implied, testbeds based on real mobility, change the nodes physical position of signal radiation, either by participants carrying mobile devices, appropriate instructed robots or in a discrete form just by switching between different propagation locations electrically.

Channel emulation: In contrast real mobility, the approach of channel emulation, bases on stationary fixed emulation nodes, whose radio signals are altered electrically to meet the properties of an equivalent time varying radio channel among the nodes.

Logical connectivity: Relying on stationary fixed emulation nodes, but increasing the degree of channel abstraction further, results in a simple node connectivity according to the virtual network topology. Depending on the degree of abstraction, the logical connectivity can be for instance on packet or MAC-Frame level.

Miniaturization: The propagation environment is reduced to the size of a single room to avoid unintended interference. Possible deviations to the real-world size: Nodes may act in the antenna near field, differences for power delay spread, differences for the channel coherence time.

Bandwidth Saturation: Addresses the mismatch of overall network throughput for emulation. Occurs if the wireless medium, e.g., a 802.11 interface is emulated over a wired, e.g., 802.3 gigabit ethernet interface. Simple traffic shaping mechanism can reduce the bandwidth to the maximal desired value, but cannot generate the saturation effects which occur, if several wireless nodes try to access the wireless medium. A second kind of bandwidth saturation mismatch occurs, if mobility is emulated by simple on/off connectivity on packet/frame level with filtering tools, while the physical close emulation nodes share the same wireless channel.

Centralized control: A central server emulates the node movements, the virtual scenario environment, and if possible the actual state of the wireless medium. The nodes forward their outgoing traffic to the core server, which forwards, drops, or alters the signals according to the actual network topology and wireless medium conditions.

Distributed control: Nodes are mutual connected via a wired or wireless shared media. Each node receives all communication attempts and autonomously determines whether it accepts or rejects incoming packets, based on the actual network topology.

Hybrid Emulation: Emulation setup consisting of several physical machines, each hosting one or multiple virtual node instances.

One-to-One mapping: A physical machine that holds only a single virtual node.

Monolithic Emulation: Emulation setup consisting of a single physical machine which holds all virtual nodes. In contrast to network simulation, at least on communication layer is real implemented running on the operation system.

Virtualization Degree: Number of virtual nodes on a physical emulation machine.

Virtual Node: Set of vertical aggregated protocol instances to represent the mobile ad hoc node. E.g, a routing daemon, transport layer protocol, and a traffic generator.

Core node: Central server in a central controlled emulation testbed.

Edge node: The physical machine which holds one or more virtual nodes in an emulation setup.

Emulation Layer: The software extension of the protocol stack which adapts the Service Access Point to the desired behavior.

4 Evaluation criterion

For the evaluation of the surveyed testbeds, we apply the criterion as shown in Figure 3. The wording is chosen, so that always the maximum value for a criteria represents the desired optimum.

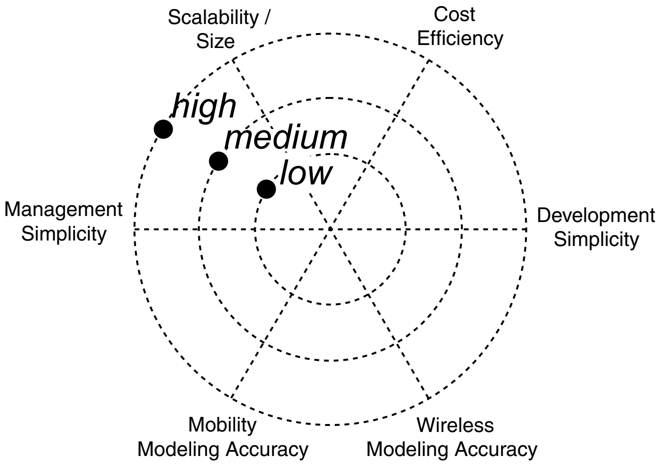

Figure 3: Graphical representation for the testbed evaluation. Circles around the center represent the different levels for fulfilling the cirtiera.

Scalability/Size: Addresses the number of nodes the testbed or emulation approach can support. Because it is not possible to evaluate the scaling factor from the outside, the reported testbed size is taken as a reference value.

Development Simplicity: Addresses the complexity of developing the testbed regarding human resources for hardware manufacturing, software coding, or porting software to the platform.

Management Simplicity: Addresses the required management capabilities in terms of human resources during a testrun.

Wireless Modeling Accuracy: Reflects the fidelity of the applied modeling approach for the wireless media.

Mobility Modeling Accuracy: Addresses the reproducibility of mobility. Nodes in the testbed may not be able to perform arbitrary mobility patterns or have strong constraints regarding velocity variations.

Cost efficiency: In terms of cost for the required hardware and software, as well as the required space for deployment.

5 Evaluation of testbeds

The following Figures shows the evaluation of the surveyed testbeds according to the criterion in Section. 4

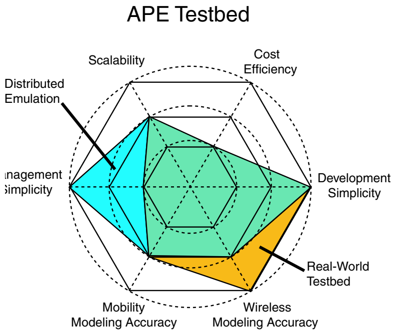

Figure 4: Evaluation for the dual use functionality as real-world and emulation testbed. See 6.1

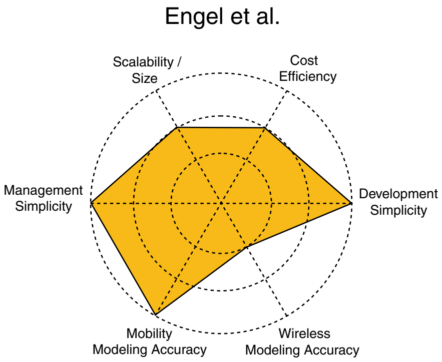

Figure 5: Virtual nodes based on MicroKernel approach. See 6.6

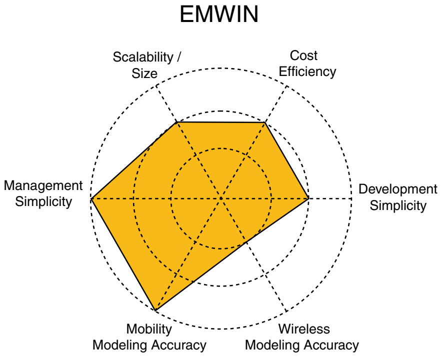

Figure 6: EMWIN Emulator. See 6.20

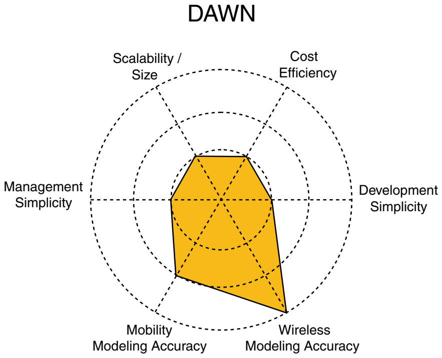

Figure 7: The DAWN testbed. See 6.10

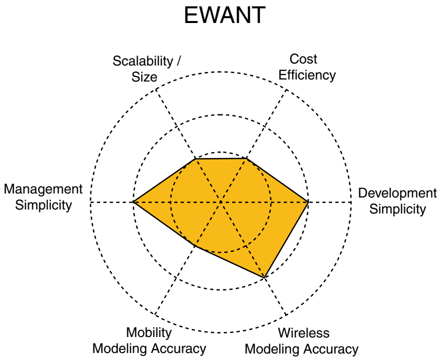

Figure 8: Real mobility with antenna switching in EWANT. See 6.8

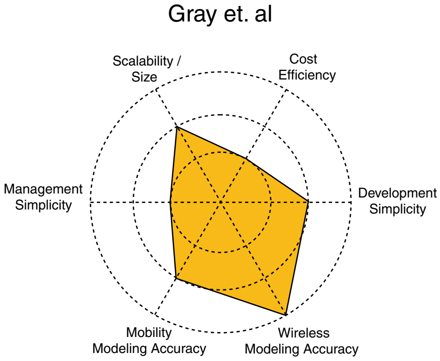

Figure 9: 33 Nodes outdoor testbed with GPS movement tracking. See 6.3

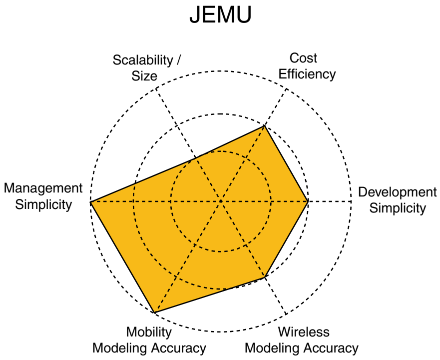

Figure 10: Centralize Controlled Emulation testbed at Trinity College. See 6.16

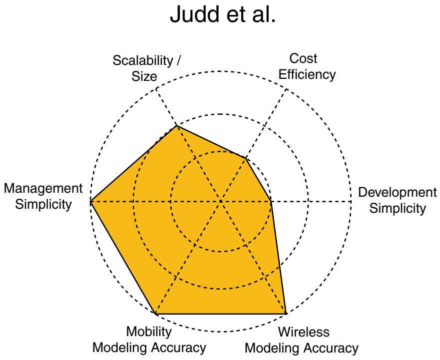

Figure 11: Emulation of the wireless channel with Digital Baseband Processing. See 6.5

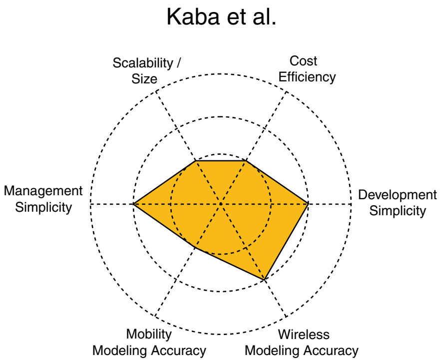

Figure 12: Channel Emulation by guiding radio signals in Coax cables. See 6.4

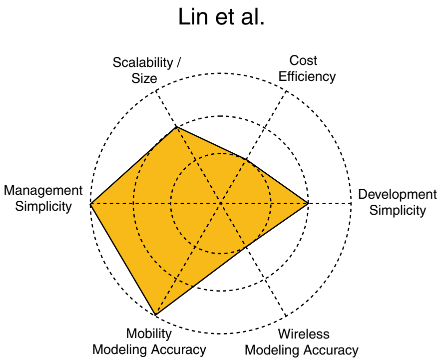

Figure 13: A dynamic topology switch for Centralized Emulation. See 6.6

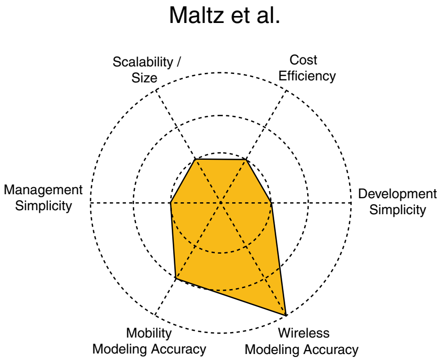

Figure 14: Real-world testbed with cars and persons. See 6.11

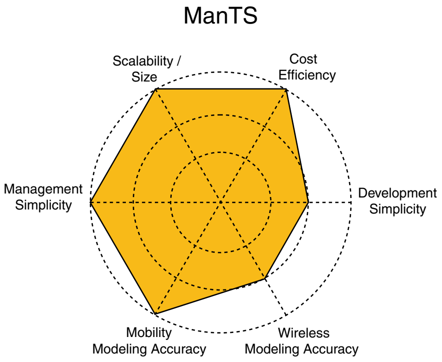

Figure 15: Hybrid emulation setup with distributed control. See 6.18

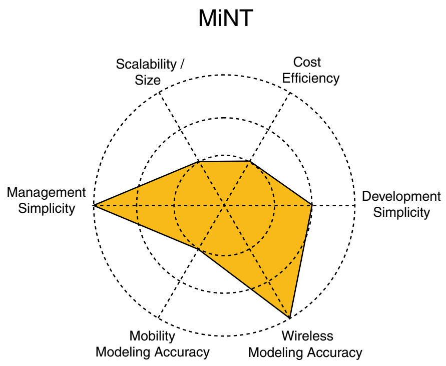

Figure 16: Miniaturized testbed with robots. See 6.21

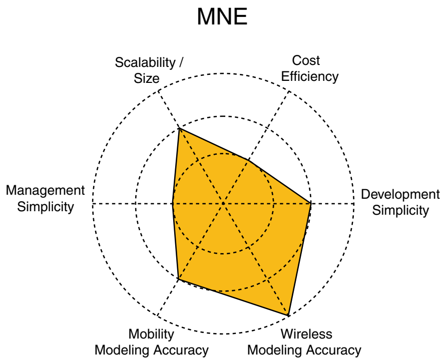

Figure 17: Real-world testbed with GPS location tracking and emulation. See 6.15

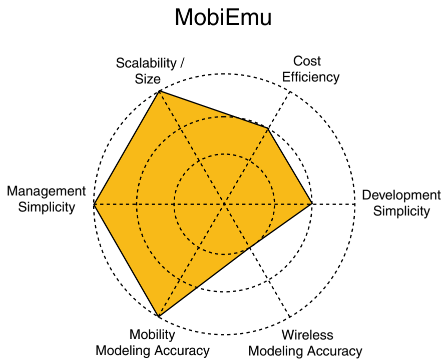

Figure 18: A distributed controlled emulation testbed with UML extension. See 6.14

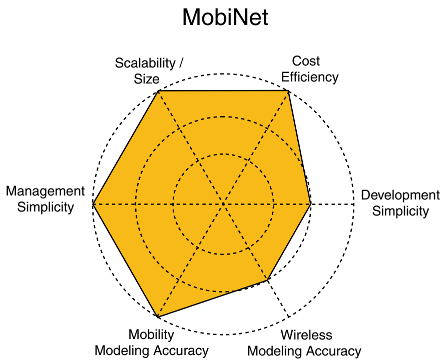

Figure 19: Centralize controlled and hybrid emulation setup . See 6.12

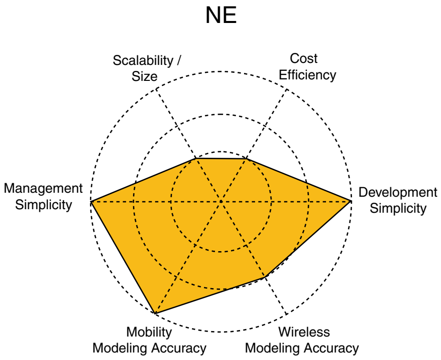

Figure 20: A distributed controlled emulation testbed with traffic shaping to adapt the wired network. See 6.19

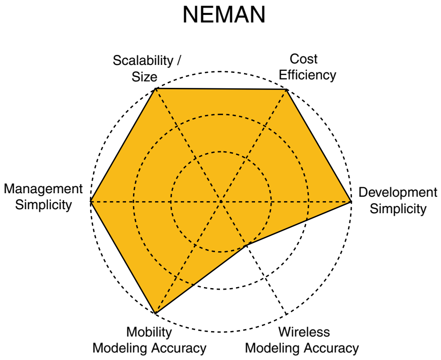

Figure 21: Monolithic emulation with Linux. See 6.24

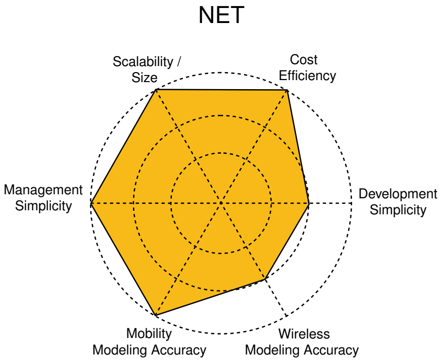

Figure 22: Distributed emulation of the shared wireless media with ”Virtual Carrier Sensing”. See 6.23

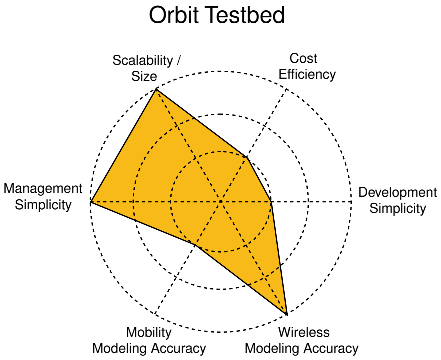

Figure 23: Large indoor grid of 400 physical nodes. See 6.2

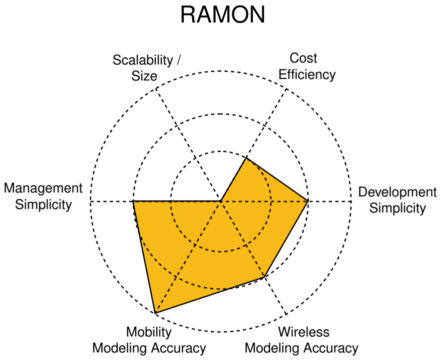

Figure 24: Testing Mobile IP with channel emulation for a single node. See 6.17

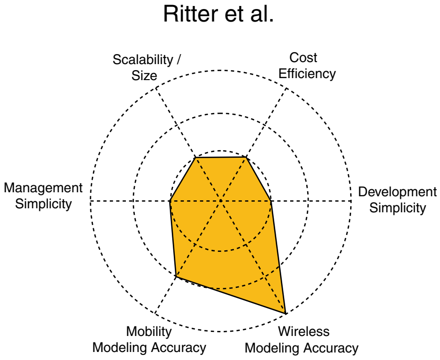

Figure 25: Real-world testbed for scatter networks. See 6.9

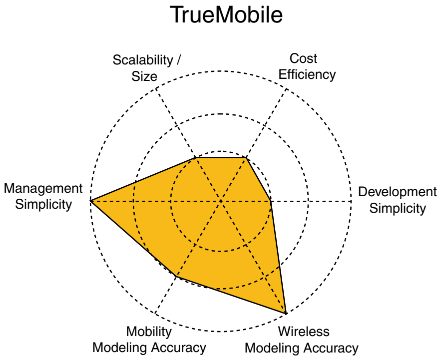

Figure 26: Indoor testbed with robots and vision based tracking system. See 6.22

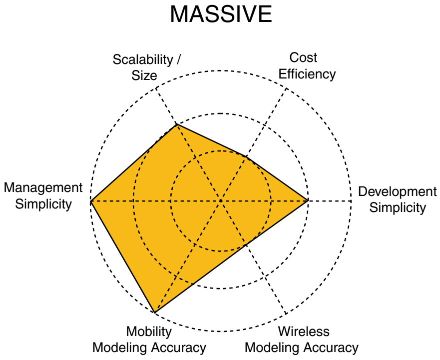

Figure 27: Distribute controlled emulation testbed, which allows to change network topology during runtime. See 6.13

6 Listing of testbeds

6.1 APE

Authors: Erik Nordström, Per Guinningberg, Henrik Lundgren

Place: Department of Information Technology, Uppsala University, Uppsala, Sweden

Description: APE is Linux based software environment, allowing to perform MANET experiments with various ad hoc routing algorithms. The APE framework was designed to run experiments on standard laptops equipped with 802.11 interfaces. The software consists out of a customized Linux distribution, which for simplicity is bootable from CD-Rom. The stand alone system provides a set of automated scripts for controlling traffic generators, as well as for the collection, aggregation, and evaluation of measurement data. Node mobility is controlled by display instructions guiding the test person throughout the experimental environment. Moreover, APE offers the functionality of a distributed emulation testbed. In emulation mode, the time driven scenario script controls node connectivity with filtering tools on frame level.

Size: biggest experiments reported 37 nodes

Date: 2002

Reference: http://apetestbed.sourceforge.net/, [6]

6.2 Orbit

Authors: Dipankar Raychaudhuri, Max Ott, Ivan Seskar, Wade Trappe, Manish Parashar, Yanyong Zhang, Henning Schulzrinne, Hishashi Kobayashi, Arup Acharya, Sanjoy Paul, Kumar Ramaswamy, K. Ramachandran, H. Kremo, Robert Siracusa, Hang Liu, Manpreet Singh, Pandurang Kamat, Jing Lei, Roy Yates, Larry Greenstein,

Place: WINLAB, Rutgers University, New Jersey, USA

Description: The ORBIT testbed consists of 400 fixed radio nodes installed indoor, forming a two dimensional array. Placed with a subspace of one meter, each physical node is logically connected to a virtual simulation node in a core network. Discrete mobility is performed, by mapping outgoing frames of the simulated nodes in real-time to a suitable radio nodes according to the actual topology. The radio nodes are equipped with two 802.11x interfaces, bluetooth, and gigabit ethernet to connect core units. For emulating the wireless component precisely, several artificial RF interferer facilitate to model noise characteristics in a repeatable manner. Extensive measurements can be performed on the physical, MAC, and network level.

Size: 400 physical nodes

Date: Since 2005

Reference: http://www.orbit-lab.org, [7]

6.3 Gray et al.

Authors: Robert S. Gray, David Kotz, Calvin Newport, Nikita Dubrovsky, Aaron Fiske, Jason Liu, Christopher Masone, Susan McGrath and Yougu Yuan.

Place: Dartmouth College, Hanover, New Hampshire, USA

Description: Real-World Testbed for evaluation of ad hoc routing protocols. Based on laptops equipped with 802.11 interfaces and GPS receivers. Software architecture provides dual use functionality as distributed controlled emulation.

Size: 33 real

Date: June 2004

Reference: [8]

6.4 Kaba and Raichle

Authors: James T. Kaba and Douglas R.Raichle

Place: Princeton, New Jersey, USA

Description: Standard notebooks are equipped with 802.11b cards and set on a lab table. The RF signals of the wireless interfaces are feed into coaxial cables which are interconnected by resistors, splitters and combiners to set up the network topology. Nodes are physically separated on signal level by additional fixed and variable value attenuators to decrease transmit and receive power.

Size: 4 real nodes

Date: 2001

Reference: [9]

6.5 Judd and Steenkiste

Authors: Glenn Judd and Peter Steenkiste

Place: Carnegie Mellon University, Pittsburgh, USA

Description: The radio signals of notebooks equipped with 802.11b wireless interfaces are mixed down to a baseband signal of 2 to 24 MHz. After digitizing each nodes baseband signal, it is feed to a centralized DSP engine. This FPGA uses common radio propagation models to calculate the physical received signals for each signal path between each node pair, including possible objects in between. Virtual mobility is handled within the FPGA which adapts the channel models according to the time dependent node positions. After digital to analogue conversion of the resulting base band signal, it is mixed up and feed back to the appropriate node's wireless interface. The digital baseband emulation facilitate to emulate even small scale fading, as well as different antenna patterns.

A second improved version aims to emulate a broader channel of up to 100 MHz, thus allowing to combine different devices acting in the addressed frequency range,i.e., devices supporting 802.11g or a portion of 802.11a.

Size: 3 physical nodes for the prototype, 15 physical nodes for the improved emulator.

Date: 2003

Reference: Webpage: http://www.cs.cmu.edu/ prs/emulator/index.html,[10]

6.6 Lin et al.

Authors: Tao Lin, Scott F. Midkiff, Jahng S. Park

Place: Blacksburg, Virginia, USA

Description: A central Linux based emulation machine is equipped with several wired network interfaces to form a dynamic network switch. Exempt from an additional emulation layer, each connected node can communicate depending on the mobility scenario controlled forwarding table of the switch. The loss property of the wireless channel is modeled by a two-state Markov chain for the packet drop rate. The bandwidth adaptation from the wired to the wireless domain is performed by shaping each node's egress traffic by a leaky-bucket token buffer model.

Size: 4 nodes

Date: November 2002

Reference: [11]

6.7 Engel et al.

Authors: Michael Engel, Matthew Smith, Sven Hanemann and Bernd Freisleben.

Place: Deptartment of Mathematics and Computer Science, University of Marburg, Germany

Description: The testbed addresses optimizations concerning the virtualization degree for Hybird Emulation. The proposed emulation architecture bases on a L4 Microkernel running on each physical node, which is capable of running up to 10 L4 kernel instances in userspace. Each virtual node, represented by a user space instance is connected via a virtual network adapter to a common packet multiplexer which models the properties of the wireless medium.

Size: 5-10 virtual nodes per physical node.

Date: September 2004

Reference: [12]

6.8 EWANT

Authors: Sagar Sanghani, Timothy X Brown, Shweta Bhandare, Sheetalkumar Doshi

Place: University of Colorado at Boulder, USA

Description: The testbed EWANT is based on miniaturization the propagation environment to the size of a single room. The radio signal of each physical 802.11b node is attenuated and feed to a multiplexer which is connected to four different located antennas spread over the labtable. The switching process at the multiplexer unit imitates a node moving between four different locations in discrete fashion.

Size: 4 real nodes

Date: March 2003

Reference: [13]

6.9 Ritter et al.

Authors: Hartmut Ritter, Min Tian, Thiemo Voigt, Jochen Schiller,

Place: Freie Universität Berlin, Germany

Description: The testbed consists out of so called ”Embedded Wireless Modules”, which are based on a Motorola 68HC912 core controller quipped with bluetooth and a 433 MHz RF-module. The measurements in this person guided real-world testbed addresses vertical- and handover times between different bluetooth piconets.

Size: 5 real

Date: October 2003

Reference: [14]

6.10 DAWN

Authors: Ram Ramanathan, Regina Hain,

Place: Internet Research Department, Cambridge, Massachusetts, USA

Description: The person guided real-world testbed DAWN is based upon the LR 4000 embedded router from Nokia Wireless Router, which is equipped with a 2.4 GHz spread spectrum radio interface. The person guided real-world testbed addresses measurement for different power control algorithms and QoS support within MANETs for voice communication.

Size: 10 physical nodes

Date: September 2000

Reference: [15]

6.11 Maltz et al.

Authors: David A.Maltz, Josh Broch, David B. Johnson

Place: School of Computer Science, Carnegie Mello University, Pittsburgh, USA

Description: One of the earliest real-word testbeds covering experiments on Mobile-IP, TCP and DSR performance in a MANET environment. The testbed consists out of a mixture of 5 hand carried and 2 vehicle mounted nodes. Communication is based on 900 MHz Wave Lan cards, as well as on wireless 2.4 GHz point-to-point link connecting parts of ad hoc network with a central office.

Size: 8 physical

Date: March 1999

Reference: [16]

6.12 MobiNet

Authors: Priya Mahadevan, Adolfo Rodriguez, David Becker, Amin Vahdat

Place: Department of Computer Science, Duke University, Durham, USA and Department of Computer Science and Engineering, University of California, San Diego, USA

Description: MobiNet is centralized controlled, hybrid emulation testbed implementing an 802.11 based MAC layer. The virtual nodes placed at the edge nodes run a native IP stack where the traffic is forwarded to one or more centralized core control nodes. Layers beneath the network layer are therefore centralized emulated which requires appropriate defined modules, e.g., a DSR routing module at the core control nodes. As a consequence, the multihop forwarding process is performed centrally, relieving the edge nodes of computational complexity, which increases the degree of virtualization. The centralized approach incorporate co-channel interference, i.e., the core nodes discard colliding packet at receiver side, if their power level is below a certain threshold.

Size: 200 virtual nodes on 2 physical nodes with a single core controller

Date: June 2005

Reference: [17]

6.13 MASSIVE

Authors: Michael Matthes, Holger Biehl, Michael Lauer and Oswald Drobnik

Place: Department of Computer Science, J.W. Göethe-University Frankfurt/Main, Germany

Description: A distributed emulation testbed, allowing to emulate several virtual MANETs in real-time concurrently. A central visualization server additionally allows inline editing during runtime, i.e., to control the virtual network topology by drag and drop mechanisms for the displayed mobile devices. Particular interesting is the script based creation of movement patterns, which allows to emulate complex mobility scenarios, such as the presence of attractive forces or movement patterns assigned to a group of nodes.

Size: 13

Date: January 2005

Reference: [18]

6.14 MobiEmu

Authors: Yongguang Zhang and Wei Li

Place: HRL Laboratories, Malibu, California and Department of Computer Science at the University of Texas at Austin

Description: MobiEmu is a distributed controlled emulation testbed. Connectivity changes are indicated by a central server, which also displays the actual network topology. Control information and measurement data can be separated on individual interfaces, allowing to run experiments on a real 802.11 interface while the management information are delivered on a separate wired interface. As an extension, MobiEmu also facilitates the use of User Mode Linux (UML), which allows to run several virtual node instances on a single physical machine.

Size: 50 physical

Date: June 2002

Reference: [19]

6.15 MNE

Authors: Joseph P. Macker, William Chao, Jeffery W.Weston

Place: Naval Research Laboratory, Washington, DC

Description: The Mobile Network Emulator (MNE) offers a dual use functionality as a real-world, as well as distributed emulation testbed based on packet filters. The physical nodes are based on standard laptops equipped with 802.11 radio interfaces. For the emulation mode, each node locally determines its position periodically, either by its own random movement process, by reading a ns-2 mobility file or replaying position information from a recorded GPS log file. The frequently updated position information is send via a reliable multicast back channel to the remaining nodes, allowing them to determine link propagation including possible obstacles.

Size: 10

Date: October 2003

Reference: http://downloads.pf.itd.nrl.navy.mil/proteantools/mne-scripts.html, [20]

6.16 JEMU

Authors: Juan Flynn, Hitesh Tewari, Donal O'Mahony

Place: Department of Computer Science, Trinity College, Dublin, Ireland

Description: JEMU is a central controlled emulation testbed. Each physical node in the network runs a stack instance comprising routing and MAC layer, as well as an appropriate designed radio layer, which forwards the outgoing frames to a central emulation controller. The controller runs and displays the mobility scenario and determines from virtual distance and transmit powers whether incoming frames have to be dropped due to overlapping time intervals.

Size: 12 real nodes

Date: January 2002

Reference: [21]

6.17 RAMON

Authors: Edwin Hernandez and Abdelsalam (Sumi) Helal

Place: Computer and Information Science and Engineering Department, University of Florida, Gainesville, USA

Description: RAMON can be classified as a channel emulator to address the evaluation of Mobile-IP mechanisms. The testbed consists of three 802.11b Access Point, each equipped with a computer controlled RF attenuator and a single stationary node. Node movements will therefore be emulated by adjusting the attenuation level of the Access Points. This emulates the time varying SNR values. Because it support only a single node, multi-hop communication is not possible.

Size: 1 real node

Date: November 2002

Reference: [22]

6.18 ManTS

Authors: Rui He, Man Yuan, Jianping Hu, Hong Zhang, Zhigang Kan, Jian Ma

Place: School of Computing Science, Bejing University of Aero. and Astro, Bejing, China

Description: ManTS can be considered as a hybrid emulation setup based on centralized control mechanism. The physical emulation machines hosting the virtual nodes are called *Virtual Node Container* where machines with a *one-to-one* mapping are called *Observed Nodes*. Both types are connected via a wired shared medium, together with the *Environment Control Server*, which delivers medium information upon request. Each's node stack is extended by an 802.11b emulation layer, which initiates each communication attempt by a medium request at the *Environment Control Server* to emulate mobility or possible collision and saturation effects. Also *virtual nodes* communicating within their container environment have to consult the *Environment Control Server* to divide the overall network bandwidth precisely.

Size: no details given

Date: September 2003

Reference: [23]

6.19 NE

Authors: Weiguo Liu, Hantao Song

Place: Department of Computer Science and Engineering, Bejing Institute of Technology, Bejing, China

Description: Ne is a distribute controlled emulation testbed based on wired ethernet. Link status information are broadcasted by a central server to update the local connectivity matrixes of the edge nodes. The emulation layer at each edge nodes shapes the outgoing traffic for bandwidth adaptation and adds frame delay with the help of a delay queue. The loss rate for the wireless medium is realized at receiver side, possibly including physical object in the emulation space.

Size: no details given

Date: July 2002

Reference: [24]

6.20 EMWIN/EMPOWER

Authors: Pei Zheng, Lionel M. Ni

Place: Department of Computer Science and Engineering, Michigan State University, Michigan, USA

Description: The mobile wireless network emulator EMWIN is based on the emulation framework EMPOWER [25], which follows the style of a hybrid emulation testbed with distributed control mechanism based on a wired network. From a predefined mobility scenario the overall connectivity matrix is derived forming the input for all virtual nodes. Effects of a real 802.11 interface are added by the emulation layer which introduce optional the RTS/CTS overhead and checks during runtime channel occupancy at neighboring nodes for the backoff algorithm.

Size: 48 virtual nodes based on 8 physical machines.

Date: September 2002

Reference: [26]

6.21 MiNT

Authors: Pradipta De, Ashish Raniwala, Srikant Sharma, Tzi-cker Chiueh,

Place: Department of Computer Science, Stony Brook University, Stony Brook,New York, USA

Description: The MiNT testbed apply 802.11 based radio nodes mounted on remote controlled robots. To avoid unintentional interference of random existing noise sources, the whole testbed is set up in a single laboratory room. To achieve multihop communication within close proximity, wireless interfaces with adjustable transmit power and radio signal attenuators are used for lowering the transmit power. Remarkable is the option of a dual use emulation, where the physical layer is real, while the remaining upper layers are part of a ns-2 simulation. This facilitates to analyze the fidelity of indoor propagation models with results from the live experiment. Mobility in the first prototype was limited due to the fact that the robots receive their control information via cable which did not allow complex movements. An extended prototype, MiNT-m, supports full topology reconfiguration and unrestricted node mobility. Therefore, nodes are tracked by a vision-based system, including a collision avoidance mechanisms.

Size: 8 physical

Date: March 2005

Reference: http://www.ecsl.cs.sunysb.edu/mint/, [27]

6.22 TrueMobile

Authors: David Johnson, Tim Stack, Russ Fish, Dan Flickinger, Rob Ricci, Jay Lapreau

Place: University of Utah

Description: TrueMobile is the wireless, mobile, extension to the Emulab testbed, which provide access to a variety of experimental environments. In this miniaturized indoor testbed, mobile robots carry Mica2 motes which are equipped with a 900 MHz power reduced radio interface for multi-hop communication. A second 802.11b interface serves as a separate control network. Localization is achieved by a vision based tracking mechanism to support collision free path planning for the robots.

Size: 16 physical Nodes

Date: April 2005

Reference: http://www.emulab.net, [28]

6.23 NET

Authors: Kurt Rothermel, Daniel Herrscher, Steffen Maier, Illya Stepanov, Franz Fabian, Martin Brodbeck

Place: Distributed Systems Department, Institute of Parallel and Distributed Systems, University of Stuttgart, Germany

Description: The Network Emulation Testbed (NET) is a Hybird Emulation setup based on distributed control mechanism. The NET testbed is based on a very efficient implementation of running several stack instances in parallel. This leads to a high degree of Node Virtualization of up to 30 nodes per physical machine. The traffic shaping tool for the emulation layer is called ”Net-Shaper”, which performs bandwidth adaptation and the insertion of artificial delay. The wireless medium is emulated over a wired gigabit ethernet. A unique feature of NET is the remarkable approach of ”Distributed Emulation of Shared Media Networks” [29] suitable to address the 802.11 MAC layer [30]. Therefore, the emulation tool ”WILEMU” encapsulates all outgoing frames as broadcast to facilitate unrestricted mutual connectivity along the physical network. Each node holds its local view of the virtual wireless medium by calculating a ”Network Allocation Vector” (NAV) for each incoming frame. This facilitate to perform a virtual carrier sensing before accessing the medium. While the transmission time of an Gigabit Ethernet frame is much smaller than of an equivalent 802.11 frame, possible collisions can be detected by overlapping NAVs in a distributed way. Additionally NET provides the emulation of a virtual GPS interface and virtual battery condition to facilitate a broader range of test scenarios.

Size: 1920 virtual nodes on a 64-node pc cluster.

Date: 2002

Reference: available at http://net.informatik.uni-stuttgart.de/

6.24 NEMAN

Authors: Matija Puzar, Thomas Plagemann

Place: Department of Informatics, University of Oslo, Norway

Description: Is a representative for monolithic emulation. With the help of a Linux Kernel patch, the emulation platform NEAMN is able connect virtual network devices according to the GUI based topology manager.

Size: reported size of 100 virtual devices, where a higher node number is possible with little software changes. Absolute number is restricted by the computational power of the physical controller.

Date: June 2005

Reference: [31]

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