

Wireless Network Mobility Emulation over Wired Testbeds: A Review

Ramneek^{*, **}, Wonjun Choi^{*, **}, Woojin Seok^{**}

^{*}Department of Grid and Supercomputing, Korea University of Science and Technology, Daejeon, Korea

^{**}Department of Advanced KREONET Application Support, Korea Institute of Science and Technology Information (KISTI), Daejeon, Korea

ramneek@kisti.re.kr, cwj@ust.ac.kr, wjseok@kisti.re.kr

Abstract— Wireless networks technologies offer the opportunity for the users to move as they continuously use the network. Mobility has a great impact on the network performance, behaviour, and ability to provide consistent service over a wide area network. This capability exists for traditional wireless technologies such as IEEE 802.11a/b/g/n (WLAN), and also for newer technologies such as IEEE 802.16e (WiMAX). Modelling different types of user mobility and behaviour is of primary importance in evaluation of performance and testing of protocols for wireless data networks as the real capability of wireless networks lies in mobility. The evaluation of wireless research is challenging because wireless networks are complex. There is high-variability of conditions depending on environment, motion, etc. Also, to study the mobility, coordinated displacement of wireless nodes has to be monitored, which is a tedious task with a high overhead cost. Moreover, it is very important to be able to repeat the experiments, without compromising with the realism. Hence, wireless emulation is impossible if we use the real wireless hardware and infrastructure, unless the wireless communication conditions are fully controllable. By exploring the benefits and challenges of emulating wireless mobility in various existing wired testbeds, this paper attempts to facilitate the understanding of the implications of wireless emulation and designing mobility emulation framework for existing wired network testbeds.

Keywords— Emulation, Wired Testbed, Wireless Testbed, Mobility, Emulab.

I. INTRODUCTION

A large number of mobile devices including smartphones, tablets, notebooks, etc. are using wireless technologies now a day. The increasing demand for wireless communication systems and the related technological advancement has led to the need for a better understanding of fundamental issues in wireless communication and their implications on the design of highly-capable wireless systems.

Evaluation of wireless networking protocols and algorithms can be done using simulation, emulation or real wireless testbed. The first and most intrinsic choice for addressing the issue of realism is to use the real wireless infrastructure to conduct the experiments. However, this

approach suffers from the problems of repeatability and controllability because the physical environment has a direct impact on the behaviour of physical layer and this makes these conditions nearly impossible to reproduce. Due to the above-mentioned issues, many researchers prefer the use of software simulation. Simulation is a good choice for gaining insight into the system behaviour and performance. It helps to study the system performance conceptually and gives an indication about the existing issues before the actual hardware deployment. However, it lacks realistic duplication of the physical layer and ignores inter-layer communications. Some of the popular network simulators are NS2, NS3, OPNET, QualNet, J-Sim, NETSIM, REAL, etc., and the issues related with these simulators have been well studied in literature [1].

Though Simulation solves the problem of repeatability, configurability and management, it does not reflect realism. The highly dynamic characteristics of the mobile wireless networks does not allow one to depend upon network simulation or a testbed. The above-mentioned issues with simulators and real wireless testbeds, have motivated many researchers to adopt emulation as a means of evaluation. Network emulation provides a middle ground between simulations and the real testbeds. Emulation enables the test and evaluation of real network protocols and applications in a controllable environment that is a combination of hardware and software.

The comparison between the three techniques in terms of various parameters has been shown in Table-1. Therefore, in addition to the repeatability and manageability as in case of simulations, emulation also addresses the issue of realism by leveraging the physical layer emulation. However, one main drawback is the lack of support for the emulation of network topology and mobility, which are very important for research on mobile wireless network. Therefore, we have chosen to study the emulation of mobility in the wired testbeds.

The rest of paper is organized as follows: Section II describes the motivation behind the current study, followed by

a description of the challenges associated with wireless emulation in Section III; Section IV provides a brief review of various testbeds that were examined as a part of this study; Section V provides a comparative review of various testbeds, and finally we conclude the paper in Section VI.

TABLE 1. EVALUATION PARAMETERS

Properties	Type of Evaluation Platform		
	Simulation	Real Wireless Testbed	Emulation
Realism	Low	High	Medium
Repeatability	High	Low	Medium
Ease of Use	High	Low	Medium
Scalability	High	Low	High
Cost	Low	High	Medium

II. MOTIVATION

Emulab is a network testbed, extensively used in computer science for research in the field of networking and distributed systems [7]. The primary installation at the University of Utah is run by the Flux Group and there are also a number of installations of Emulab in different parts of the world.

KREONET-EMULAB [8][9] is currently hosted at the Korea Institute of Science and Technology Information (KISTI), Daejeon, Korea. It is based on the Utah Emulab software, allowing the system allocation and topology configuration for the end users. The current Emulab infrastructure at KISTI allows the users to create various network topologies using the Web-based graphical user interface, as shown in Figure 1. It enables the evaluation of various network protocols, e.g. IPV6, TCP performance tests, etc. The current testbed configuration consists of 42 Dell R710 servers, having 5 network interfaces. One of the interfaces is used for the control and the remaining four are used as experimental links. Figure 2 shows the current. The hardware and software features of Kreonet-Emulab have been summarized in Table II.

Emulab at KREONET currently supports the emulation and performance evaluation of various wired network protocols, allowing the user to define various network parameters such as packet loss, bandwidth, latency, queue-size, etc. In order to extend the capability of the current testbed to support the wireless network emulation, we reviewed a number of existing testbeds that support wireless emulation. As there are a number of challenges associated with the wireless emulation (as discussed in the next section), we particularly focus on how the existing wired testbeds can be

extended to support the wireless experiments and user mobility.

TABLE 2. KREONET EMULAB (KISTI) FEATURES

System/Network Hardware	
-	Dell R710 Server/Bare Metal
-	5 NICs for each Server : 1 for Control, 4 for Experimental Link
-	Gateway Router-Cisco 3750
-	Experimental Switch-Cisco 4507 (48 ports * 4)
-	Control Switch-Cisco 2900 (48 ports *1)
-	Remote Power Control
Software Specifications (Operating Systems)	
-	CentOs
-	Ubuntu
-	FreeBSD
-	Windows

III. CHALLENGES IN WIRELESS NETWORK EMULATION

Wireless network technologies have advance a lot since past few years and hence are extensively being deployed in many different types of mobile devices including laptops, notebooks, smartphones, tablets, etc. Wireless networks enable the mobile users to move freely as they use the network. This capability exists for traditional wireless technologies such as IEEE 802.11a/b/g/n (WLAN), and also for newer technologies such as IEEE 802.16e (WiMAX). Due to time variant characteristics and complexity of wireless networks, the evaluation of wireless research is highly challenging. There is high variability of conditions due to a number of factors such as node mobility, interference and fading, etc. Interference between the radio signals of same frequency can lead to a discrepancy in the observed network throughput and signal strength. Such factors can lead to erroneous experimental results. In addition, high management overhead has to be incurred to coordinate the controlled movement of the mobile nodes. Hence it becomes highly challenging to achieve repeatability without compromising with the realism achieved by using the actual wireless network hardware.

Hence, a robust testbed should be able to support repeatable and controllable experiments, without sacrificing the realism achieved by using the real hardware in case of emulation. In addition, the users must be able to capture the real effects of radio spectrum sharing and fading on the evaluation results, without any interference outside the experimental setup. In addition, there should be provision for emulating the node mobility, and related mechanisms such as vertical and horizontal handovers, hidden terminal effect, etc. Experimental wireless evaluation in a test environment must correspond to an actual deployment, and there should be no restrictions based on the underlying hardware or the operating system being used. A good emulation framework should be low cost, have ease of management, resource efficiency, and

the user should have a good experimental control, i.e. topology and application configuration.

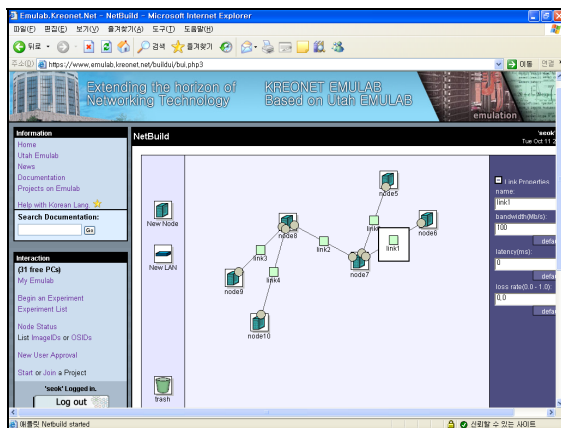


Figure 1. KREONET EMULAB experimental setup using the Web-based GUI

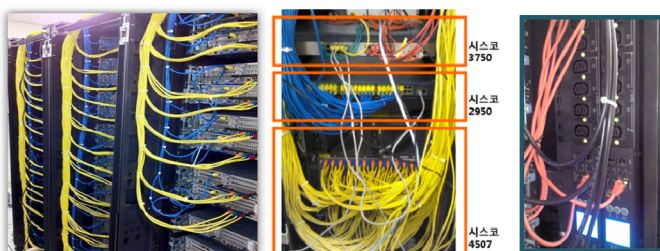


Figure 2. Emulab Setup at KISTI (42*Dell R710 servers, Cisco Switches, Remote Power Control, from left to right respectively)

IV. EXISTING TESTBEDS

In this section, we describe in brief, the major testbeds that we examined as a part of this review.

ORBIT: It is a fixed testbed consisting of 64 fixed nodes, with two IEEE 802.11 a/b/g radio interfaces each, arranged on 8 by 8 grid [3]. As the nodes are static, so the real physical mobility cannot be performed using the main radio grid. Hence, the mobility is emulated by spatially switching over an array of 128 radio interfaces of the nodes present in the grid. As the time progresses, the changing position of the moving node is represented by having the network layer of the virtual mobile node resides on the same node, but the link and physical layers of different grid node. ORBIT is one of the first mobility emulators, capable of hosting repeatable mobility emulations without any kind of human assistance. The results are more accurate due to the use of actual hardware, i.e. 802.11 radio interfaces. However, due to the fixed number of grid nodes, the experiments might not be highly scalable. In addition, if more than one nodes are moving simultaneously, there can be interference due to cross flows of traffic. In addition, more finetuned implementation of the framing and error patterns is required, for more realistic implementations.

EMWIN [4] is an IP-based wireless mobile emulation framework, capable of supporting the dynamic topologies and movement of the mobile nodes. Its design principle is based on the emulation framework called EMPOWER (EMulation the Performance Of Wide aRea networks), which facilitates the mapping of a target mobile wireless network topology and configuration to an emulation configuration in a laboratory based network consisting of a number of emulator nodes, each of which is able to emulate multiple mobile hosts. It uses a simple and efficient approach known as neighbour table to emulate the mobility of mobile hosts. Each Virtual Machine Node (VMN) in EMWIN maintains a neighbour table containing information about the VMNs accessible to it. Hence, this enables a time variant wireless network topology to be emulated over a wired network. The strength of EMWIN lies in the fact that it makes the use of low cost commodity computer systems to provide fully repeatable and controllable environment for testing and evaluation of wireless network ideas and protocols. In addition, it allows the VMNs to be configured easily via the end user programs. However, in this case, emulating the layers of mobile wireless networks is a critical design issue. In addition, the processing of neighbour tables can incur additional complexity in case of large and dynamically changing topologies.

QOMET: It is a robust and flexible 2-stage scenario driven Wireless Network emulator that accurately reproduces a user defined WLAN scenario using a wired network [2]. In the first stage, a network quality degradation (ΔQ) description is created from a real-world scenario defined by the end user. Next, the ΔQ description generated in the previous step is transformed into an emulator configuration that is used during the actual emulation process. The emulation in QOMET is based on two main libraries known as deltaQ and wireconf. The deltaQ library is used in the first stage to compute the values of ΔQ parameters corresponding to different connections in the user scenario, while the wireconf library is used for the link level configuration of the emulator. Different types of motion currently supported by QOMET include linear, circular, rotation, random walk, and behavioural motion [5]. The main advantage of QOMET is that it provides the use of real 802.11a/b/g WLAN interfaces, and hence is capable of emulating realistic topologies in which the effects radio interference and dynamically changing environmental factors is also taken into consideration. However, in case of QOMET, the user-defined parameters are mapped to the lower layer specifications for wireless network. However, the end user is required to know the various physical layer parameters such as noise power, bandwidth, and loss rate, etc., which may be difficult for the user and should be defined in an inbuilt manner depending on the wireless technology being emulated.

MobiNet [6] is an emulation platform that supports the testing and evaluation of Ad Hoc and Wireless networks, using a LAN cluster consisting of edge and core nodes. The three steps involved in MobiNet emulation include topology

creation, assignment of virtual nodes to edge nodes, and pipes to core nodes respectively, and the execution of the user application as the final step. The edge nodes support the end user OS and applications, while the core nodes emulate the topology and routing related network characteristics. The wireless network mobility is implemented by a mobility module, which is a user level application that generates the position of nodes at various time steps and a neighbour list containing the details about the neighbouring nodes within the transmission range. MobiNet supports the emulation of various wireless MAC layer and Ad Hoc routing protocols and features such as congestion, queuing, traffic models, space propagation model, etc. MobiNet infrastructure is highly flexible and extensible as it allows the end user to evaluate various MAC layer and routing protocols, and various mobility models. In addition it is highly flexible, as it can emulate hundreds of virtual nodes using a few edge and core nodes. However, it lacks the support for real wireless (802.11) network hardware support, and emulates the physical layer by supporting the models such as two-ray reflection model, free space ground propagation model, etc.

NEWS [10] is a wired network testbed that supports the performance evaluation of MANETs using a finite-state discrete Markov chain, whose parameters are derived from the wireless network attributes such as shadowing, transmission power, fading, and other link characteristics. Its design is an extension of MANE [11], which is a mobile Ad Hoc network emulator. It consists of a number of test nodes, arranged in a cluster, managed by a MANE server, which is responsible for supervising the events in each cluster. NEWS testbed extends the above implementation to incorporate the effects of fading, modulation, etc., which are very important for obtaining accurate results corresponding to real world scenarios. The data from each test node flows through one of the servers, which allows controlling the wireless topology and various link effects. Although NEWS has extensive support for emulating the fading effects, the system has its associated complexity and a limited support for various wireless network mobility models.

MobiEmu [12], a software platform for mobile Ad Hoc network testing and analysis, consists of a number of Linux machines, representing n mobile nodes in the emulation scenario. As the wireless mobile nodes move frequently, they often enter and exit the communication range of other nodes in the vicinity. Therefore, in order to replicate the real world scenario on the testbed network, packet filters are installed and removed dynamically. MobiEmu emulation is scenario-driven, as the end user has to input the details about the location and the movements of each node. It also provides a GUI component where the end user can visualize the network in action and control the various components. MobiEmu should preferably be used for testing, but not for performance evaluation, as it does not emulate the MAC and the physical layer.

MiNT [13] is a miniature version of a large wide spread wireless testbed. Due to the large coverage area of wireless radio signals, and mobility of the nodes in a wireless network, a real wireless testbed should be spread over a large physical space. MiNT significantly reduces this space and efforts required to set up a multi-hop wireless network topology. Similar to many other wireless testbeds, it consists of a set of mobile nodes that communicate over one or more hops with other nodes using wireless network interfaces. The miniaturization and space saving is achieved by attenuating the radio signals on the transmitter and the receiver. This not only reduces the space consumption, but also allows for finetuned management of the testbed. Attenuation also helps to prevent the interference that might have been caused by the presence of other wireless nodes in the vicinity of the testbed. In addition to the above features, it allows the end user to execute NS2 [14] simulation scripts, with the link layer, MAC, and the physical layers in the simulation replaced by the real emulation hardware. The main advantage lies in the fact that the user needs to make some minimal changes in the existing simulation scripts, but the realism achieved in the testing and performance is extensive. MiNT also facilitates a wide experimental control, allowing the researchers to control various topology, application, and mobility configurations, and control various network wide parameters. It also supports full-fledged packet tracing, aggregation and visualization, in order to aid the performance analysis. The main limitation, as mentioned in [13] is that the current prototype has a limited support for the node mobility due to the use of desktop computer as the emulation nodes.

V. COMPARATIVE REVIEW OF EXISTING TESTBED

All of the studied testbeds try to solve the problem of emulating wireless network mobility on wired testbeds; however each of them has its own advantages and drawbacks. In case of QOMET, the user-defined parameters are mapped to the lower layer specifications for wireless network. However, the end user is required to know the various physical layer parameters such as noise power, bandwidth, and loss rate, etc., which may be difficult for the user and should be defined in an inbuilt manner depending on the wireless technology being emulated. In case of EMWIN, a critical design issue is emulating the different layers of mobile wireless networks. In case of QOMET, the use of real wireless interfaces makes it closer to the real wireless scenario, but emulating a number of mobile nodes simultaneously can be a cumbersome process. In case of ORBIT, the results are more accurate due to the use of actual hardware; however, due to the fixed number of grid nodes, the experiments might not be highly scalable. In addition, multiple mobile nodes can cause interference. In contrast, MobiNet can emulate hundreds of virtual nodes using a few edge and core nodes. However, it lacks the support for real wireless (802.11) network hardware support, and emulates the physical layer by supporting the models such as two-ray reflection model, free space ground propagation model, etc. In addition to the features provided by

these testbeds, MiNT allows the end user to execute ns2 simulation scripts, with the link layer, MAC, and the physical layers in the simulation replaced by the real emulation hardware. The main advantage lies in the fact that the user needs to make some minimal changes in the existing simulation scripts, but the realism achieved in the testing and performance is extensive. In addition, it also supports extensive experimental control and full-fledged packet tracing, aggregation and visualization, in order to aid the performance analysis.

Each of the studied testbeds has its own key points, which should be taken into consideration, depending on the experiment requirements. Note that there are a number of additional wireless emulation testbeds; however, the main focus of our study was on the existing wired testbeds, that have been extended to support the wireless emulation, particularly focusing on the physical layer characteristics and the node mobility.

VI. CONCLUSIONS

In this paper, we presented a critical analysis of the existing wired testbeds with respect to the wireless network emulation, focusing on wireless mobility. The experimental results of wireless evaluation in a test environment must match with an actual deployment. This makes the testing and performance evaluation of wireless network protocols and algorithms to be very challenging. A good emulation framework should be low cost, have ease of management, resource efficiency, and the user should have a good experimental control, i.e. topology and application configuration. A good wireless emulation framework must exhibit realism and repeatability simultaneously.

ACKNOWLEDGMENT

This work has been supported by the research project: Collaboration Platform Service Technology Development and Application (K-15-L01-C04-S03) of Advanced KREONET Centre, Korea Institute of Science and Technology Information (KISTI), Daejeon, Korea

REFERENCES

- [1] A.Kumar, S.K.Kaushik, R.Sharma and P.Raj, "Simulators for Wireless Networks: A Comparative Study," *International Conference on Computing Sciences (ICCS)*, vol., no., pp.338,342, 14-15 Sept. 2012.
- [2] R. Beuran, J. Nakata, T. Okada, Lan Tien Nguyen, Yasuo Tan and Y. Shinoda, "A Multi-Purpose Wireless Network Emulator: QOMET," 22nd International Conference on Advanced Information Networking and Applications, (AINAW), pp. 223,228, 25-28 March 2008.
- [3] Kishore Ramachandran, Sanjit Kaul, Suhas Mathur, Marco Gruteser, and Ivan Seskar, "Towards large-scale mobile network emulation through spatial switching on a wireless grid", In Proceedings of the 2005 ACM SIGCOMM workshop on Experimental approaches to wireless network design and analysis (E-WIND). ACM, New York, NY, USA, pp. 46-51, 2005.
- [4] Pei Zheng and Lionel M. Ni, "EMWIN:: emulating a mobile wireless network using a wired network", In Proceedings of the 5th ACM international workshop on Wireless mobile multimedia (WOWMOM). ACM, New York, NY, USA, pp. 64-71, 2002.

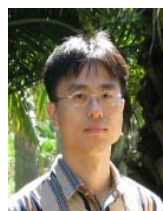
- [5] R. Beuran, S. Miwa and Y. Shinoda, "Behavioral Mobility Model with Geographic Constraints," 27th International Conference on Advanced Information Networking and Applications Workshops (WAINA), pp.470,477, 25-28, March 2013.
- [6] Priya Mahadevan, Adolfo Rodriguez, David Becker, and Amin Vahadat, "MobiNet: a scalable emulation infrastructure for ad hoc and wireless networks", 2005 Workshop on wireless Traffic Measurements and Modelling (WiTMeMo), pp 7-12, 2005.
- [7] "Emulab- Network Emulation Testbed Home", <https://www.emulab.net>
- [8] "KREONET-EMULAB", <https://www.emulab.kreonet.net>
- [9] "KREONET: Korea Research Environmmnt Open NETwork", <http://www.Kreonet.net>
- [10] H. Yousefi'zadeh, Li Xiaolong, W. Furmanski, David B. Lofquist, "Emulation of Fading Wireless Link Effects in NEWS Wired Testbed," IEEE Military Communications Conference(MILCOM), vol., no., pp.1,7, 29-31 Oct. 2007.
- [11] N. Ivanic, B. Rivera, R. Gopaul, B. Luu, D. Gwyn, R. Hardy, K. Marcus, L. Scott, G. Tran, B. Nguyen, "A scalable testbed for emulating wireless Mobile Ad-hoc Networks," IEEE Military Communications Conference (MILCOM), pp.1,5, 16-19 Nov. 2008.
- [12] Yongguang Zhang and Wei Li, "An integrated environment for testing mobile ad-hoc networks", 3rd ACM international symposium on Mobile ad hoc networking & computing (MobiHoc '02), pp 104-111, New York, USA, 2002.
- [13] P. De, A. Raniwala, S. Sharma, Chiueh Tzi-cker, "MiNT: a miniaturized network testbed for mobile wireless research," 24th Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2005), pp.2731-2742, vol. 4, 13-17 March 2005.
- [14] "The Netwok Simulator- NS-2", <http://www.isi.edu/nsnam/ns/>



Ramneek received B.Tech (Computer Science and Engineering) and M.Tech (Information Technology) from Guru Nanak Dev University (G.N.D.U) Amritsar, India in 2010 and International Institute of Information Technology (IIITB), Bangalore, India in 2013 respectively. She is currently a student researcher at Korea Institute of Science and Technology Information (KISTI), pursuing Ph.D. at the University of Science and Technology (UST), Daejeon, Korea. Her research interests include Networking and Communication (MAC Scheduling, Congestion Management in Wireless and Cellular Networks, Network Neutrality) and Cloud Computing (Openstack, IaaS, Cloud federation, Cloud Networking, SDN).



Wonjun Choi received his Bachelor's degree in Mathematics from Wonkwang University in 2006. He is currently enrolled in the integrated course in Grid and Supercomputing in the Korea University of Science and Technology. His research interests include Network Engineering, Network Communication, TCP, Cloud Federation, CCNx, NDN, SDN, and Computer Science.



Woojin Seok, received B.E, M.S, and Ph.D. from Kyungpook National University, University of North Carolina at Chapel Hill, and Chungnam National Universty, respectively. He currently works for Korea Institute of Science and Technology Information(KISTI) Advanced KREONET center. He is also adjunct professor of University of Science and Technology(UST). He is a society member of KICS and KIPS, and also committee member of Future Internet Forum (FIF) Korea and Asia Pacific Network Operation and Management (APNOM). His interesting research areas are network testbed, federation, SDN, and so on.