Mobile Ad hoc Network Testbed Using Mobile Robot Technology

To cite this article: Farkhana Muchtar *et al* 2018 *J. Phys.: Conf. Ser.* **1019** 012047

View the article online for updates and enhancements.

Mobile Ad hoc Network Testbed Using Mobile Robot Technology

Farkhana Muchtar*[12], Abdul Hanan Abdullah[1], Mohd Helmy Abd Wahab[3], Radzi Ambar[3], Hafizul Fahri Hanafi[4], Siti Nor Zawani Ahmmad[5]

[1] Faculty of Computing, Universiti Teknologi Malaysia, 81310, Skudai, Johor, Malaysia
[2] School of Computer Sciences, Universiti Sains Malaysia, 11800, Gelugor, Pulau Pinang, Malaysia
[3] Faculty of Electronic and Electrical Engineering, Universiti Tun Hussein Onn, 86400 Batu Pahat, Johor, Malaysia
[4] Faculty of Art, Computing and Creative Industry, Universiti Pendidikan Sultan Idris, 35900 Tanjung Malim, Perak, Malaysia
[5] Instrumental and Control Engineering, University Kuala Lumpur, MITEC, Persiaran Sinaran Ilmu, Bandar Seri Alam, 81750, Johor, Malaysia

E-mail: farkhana@gmail.com, hanan@utm.my, helmy@uthm.edu.my, aradzi@uthm.edu.my, hafizul@fskik.upsi.edu.my, sitinorzawani@unikl.edu.my

Abstract. MANET (Mobile Ad Hoc Network) researchers have shown increased interest in using mobile robot technology for their testbed platforms. Thus, the main motivation of this paper is to review various robot-based MANET testbeds that have been developed in previously reported research. Additionally, suggestions to heighten mobility mechanisms by using mobile robots to be more practical, easy and inexpensive are also included in this paper, as we unveils ToMRobot, a low-cost MANET robot created from an ordinary remote control car that is capable of performing a real system MANET testbed with the addition of only a few low-cost electronic components. Despite greatly reduced costs, the ToMRobot does not sacrifice any of the necessary MANET basic structures and will still be easily customisable and upgradeable through the use of open hardware technology like Cubieboard2 and Arduino, as its robot controller. This paper will also include guidelines to enable technically limited MANET researchers to design and develop the ToMRobot. It is hoped that this paper achieves its two pronged objectives namely (i) to facilitate other MANET researchers by providing them with a source of reference that eases their decision making for selecting the best and most suitable MANET mobile robots for real mobility in their MANET testbeds (ii) to provide MANET researchers with a prospect of building their own MANET robots that can be applied in their own MANET testbed in the future.

1. Introduction

The majority of existing research involving MANET evaluations have utilised simulation methods primarily. But of late, there has been an increase in awareness that the current practice of utilizing network simulators only allows for summarized assumptions in modelling the characteristics of a real system. As the researcher needs to observe the effect and influence of the MAC (Media Access Control) and the physical layer network with regards to mobility and topology changes against the links and communication quality of the MANET, it becomes clear that real mobility in MANET testbeds is vital. As such, in terms of accuracy, the data derived from this method cannot be similarly obtained by using other methods like network simulation and emulation. At

present, the number of experiments conducted in MANET testbeds are significantly lesser compared to simulation based MANET experiments [1]. There are various methods of mobility implementation that are used in MANET testbeds. These methods can be categorised into two main divisions, real mobility and emulated mobility or virtual mobility as it is also known.

The main distinctive feature of emulated mobility is due to non-physical node mobility. In other words, although real implementation of MANET testbed are performed on the data-link layer and above (application layer) but node mobility is not conducted physically. Physical node movement and topology changes are carried out through the use of emulation [2]. There are several different methods of emulated mobility such as instance migration [3], on/off connection [2], RF matrix switch [4] and the use of virtual machine technology and virtual network [5].

Emulated mobility has the advantage of being repeatable and having reproducible mobility that is almost the same as the network simulator. The mobility mechanism conducted is therefore more manageable and predictable. However, emulated mobility is unable to describe the actual MAC layer and physical layer. Hence data obtained through it is less accurate than methods that use real mobility [2]. Among the wireless testbed platforms that use emulated mobility methods are the Open-Access Research Testbed for Next-Generation Wireless Networks (ORBIT) [3], Ad-hoc Protocol Evaluation (APE) testbed with emulated mobility [6], the Carnegie Mellon University Wireless Emulator (CMUWE) [7], Castadiva [8], Mobi-emu [9], Emulab [10], MOBNET [11], MobiNet [12], the Resilience Evaluation Framework for Ad Hoc Networks (REFRAHN) [13], MeshTest [4] and WISEBED [14].

Conversely, real mobility in a MANET testbed experiment is vital in order to obtain accurate and realistic results, despite the challenging nature of implementing it. Though if done correctly, real mobility implementation is able to provide extremely accurate experimental data on the impact of mobility on a MANET [15].

Previous research on MANETs have reported the use of various approaches to provide real mobility mechanisms in their MANET testbeds. Some of the methods included the use of cars [16], taxis [17], trains [18], bicycles [19], humans [20], and remote control cars [21]. Considering that the main motivation of this paper is to review various robot-based MANET testbeds that have been developed in previously reported research, other available but non-related mechanism types will not be discussed in this paper.

Since cost and other attendant concerns of acquiring robots to perform real mobility in MANET testbed experiments is a major constraint that hinders MANET researchers from using it as an evaluation tool for MANET testbeds, this paper also serves to propose and develop a low cost robot for MANET testbeds, named as ToMRobot that is built with a remote control car and low cost electronic components.

This review paper provides a two prong approach in its objectives. In other words, this review paper will allow readers to observe how mobile technology robots have been used to create well-designed MANET testbeds while at the same time providing readers with alternative solution, that is to develop their own MANET robot at a fraction of the cost yet it is still equipped with the basic structure to function well and can easily be upgraded whenever necessary.

This paper is organized as follows. In section 2, background information on former research carried out on MANET robot platforms is detailed. Section 3 describes the development of ToMRobot and finally, in section 4, the research is summarized and the future goals of this work are out lined.

2. Literature Review

This section list out and discusses earlier robots that were used in previous MANET–based research. Table 1 provides readers with a quick glimpse on the types of robots used in MANET-based research.

It has been identified from literature [22] that most of the MANET testbed platforms have used readymade robot platforms such as iRobot Roomba/Create and LEGO Mindstorms. iRobot Roomba and Create are one of the most popular robot platforms due to several factors, including the ability to carry loads up to 2kg, the presence of basic sensors for mobile robots such as bump sensors, obstacle avoidance sensors and wheel encoders, the ease of controllability via iRobot Roomba Open Interface (ROI), the large rechargeable li-ion battery (44000 I) capacity, and the self-recharging docking station as well as their competitive prices as compared to other platforms.

Historically, the use of iRobot Roomba began when it was introduced in 2002 and it became among the earliest household robots made available to the public. It functioned as an autonomous robotic vacuum cleaner while at the same time it became a popular robot choice for robotics researchers and hobbyists that used it to be the main platform for mobile robots.

iRobot Create on the other hand was introduced in 2007 and it was based on the iRobot platform due to the popularity of iRobot Roomba amongst robotics researchers and hobbyists. iRobot Create was sold at a lower price because it did not have some of the components attached to iRobot Roomba such as a vacuum cleaning component, although the component could be added separately [22].

Table 1. List of Robots Used in MANET Testbeds

Robot Name	Robot Platform	References
Traxxas Stampede RC Car Chassis	Proteus	[24-26]
iRobot Roomba	MiNT-m	[23]
	w-ilab.t	[27-29]
iRobot Roomba/Create	Roomba MADNet	[30, 31]
	MiNT-2	[24-26]
iRobot Create	iRobotSense	[33]
	NITOS	[52]
LEGO Mindstorms	CONE	[36, 37]
	Sensei-UU	[1, 34, 35]
Acroname Garcia	Mobile Emulab	[38, 39]
	Kansei	[40, 41]
e-puck	MOTEL	[42-44]
Pioneer 3AT	CONET-IT	[45-48]
RC car chassis	CONET-IT	[45-48]
Rogue ATV	Explorebots	[51]
Lynxmotion 4WD Rove	ARUM	[49, 50]
Turtlebot2	IoT-Lab	[53]
Wifibot	IoT-Lab	[53]

iRobot Roomba and Create were usually controlled with a robot controller (usually a combination of an embedded PC and microcontroller) through the iRobot Roomba Open Interface (ROI) protocol whereby communication was enabled via a serial port on iRobot Roomba/Create including MINT-m [23], MINT-2 [24-26], Proteus Roomba [24–26], w-ilab.t [27-29], Roomba MADNet [30, 31], SCORPION [32] and iRobotSense [33].

Apart from iRobot Roomba and Create, LEGO Mindstorms was another preferred choice as a robot platform for mobile robots in the MANET testbeds. Examples of MANET testbeds that used the LEGO Mindstorms robot platform are Sensei UU [1, 34, 35] and Cone Testbed [36, 37].

The Acroname Garcia robot platform also was a popular choice in several MANET testbeds such as the Emulab Mobile (TrueMobile) [38, 39] and Kansei Testbed [40, 41]. There have also been reports of other readymade robot platforms that were utilized, such as e-puck that was used in the MOTEL testbed [42-44], the Pioneer 3AT robot platform that was used in CONET-IT [45-48], the Lynxmotion 4WD rover robot platform used in ARUM [49, 50] and the Rogue ATV robot platform used in Explorebot [51].

Previous studies revealed that the cost for robots used in said MANET testbeds ranged from between USD $3000 to USD $6,000. Understandably, procuring the higher end price range robots were a constraint for many MANET researchers. Opportunely, the ToMRobot is able to fill this research need by providing the same benefits as the existing robots, with the difference being that the ToMRobot uses different robotic components. Propitiously, said components are easily available, cheaper and easy to install by MANET researchers themselves because the required components are common ones used by hobbyists and robot makers for making mobile robots.

3. Development of ToMRobot
This section discusses the three main parts of the robot's components used in this study: (i) the mechanical component, (ii) the electronic component and (iii) software.

3.1. Mechanical Component

The mechanical component of the robot represents the robot anatomy, where it can be compared to a human body. The main element for the mechanical component of the robot is the robot chassis because it is the main mechanical structure of the robot and acts as a base to other mechanical components.

The mechanical component of this study utilizes a modified remote control car as the robot chassis. This is the cheapest solution as the RC car body serves as the robot housing and has a DC motor, gear system to increase torque and big wheels for testbed durability. Figure 1 and Figure 2 shows the original remote control car chassis before and after modification.

Figure 1. Original Remote Control Car   **Figure 2.** Modified Chassis of the Remote Control Car

3.2. Electronic Component

The electronic components are elements used as inputs and outputs to the robot. Input components such as sensors, cameras, LIDAR and IMU act as the information provider to the robot in order to determine the environmental conditions and the location of the robot.

The electronic components used in this study can be divided into two parts namely: ToMRobot and ToMDuino. The components used for ToMDuino and ToMRobot will be discussed in the next section.

*3.2.1. **ToMduino Electronic Components.*** Instead of using an Arduino board, a customized version of the Arduino board, named ToMDuino (Arduino MANET Testbed), was created for this undertaking and can be seen in Figure 3 and Figure 4.

The objectives of developing ToMduino are as follows:
  i.   **Small.** Suitably sized for the testbed robot chassis.
  ii.   **Cheap.** Cheaper than the official Arduino board with several required shields. In most cases, the Arduino shield designs are not optimized for advanced Arduino project requirements, including ToMRobot.
  iii. **Simplicity.** Avoiding the use of a combination of the Arduino board with several shields, which would increase the complexity of the setup.
  iv.   **Compatibility.** Some Arduino shields are simply not compatible or cannot be used together with other Arduino shields.

The major differences of this customized Arduino version with the official Arduino Uno R3 version are as follows:
  i.   Built-in dual h-bridge motor controller to control the ToMRobot DC motors.
  ii.   Built-in XBee socket for the ToMRobot wireless communication using the XBee protocol with a 3.3v power source board.
  iii. Specific pin header for sensors, serial connection to cubieboard2 and LCD screen.
  iv.   No generic I/O pin header-like official.
  v.   Better 3.3v voltage regulator specifically for XBee.
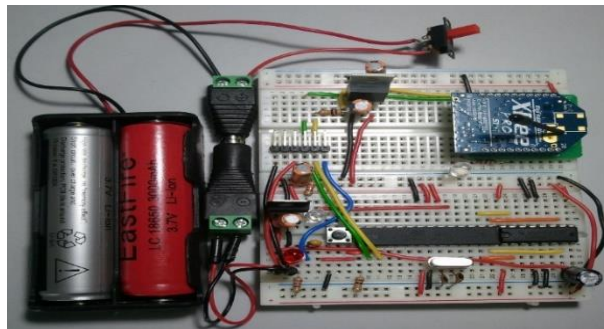
Figure 3. ToMDuino (Actual Implementation)
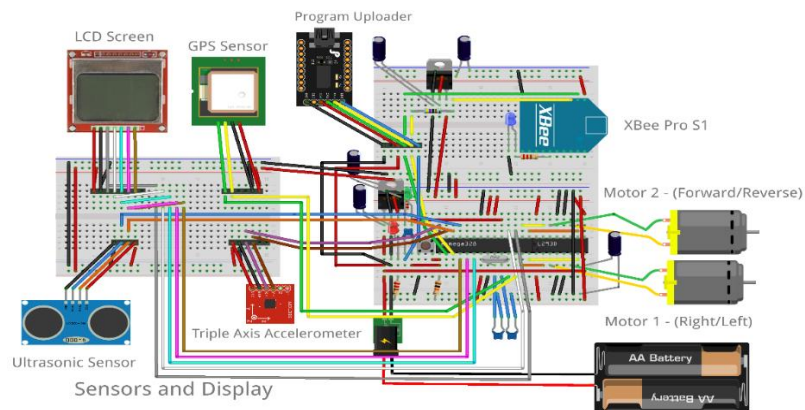
Figure 4. ToMDuino (Circuit Design)

3.2.2. ToMRobot Electronic Components. Table 2 below provide readers with a pictured view on the list of component required to build ToMRobot. Once the listed components in Table 2 have been assembled, the created robot will be similar to that in Figure 5. Figure 6 serves to illustrate how to assemble the ToMRobot.

Table 2. Description of the ToMRobot Components

Name of Component	Descriptions
Cubieboard2	To represent mobile device
USB 2.0 hub	To provide extra USB port for cubieboard2
Powerbank	To supply electric power for cubieboard2
Wi-Fi Dongle	To provide Wi-Fi connection for MANET environment testbed
XBee Pro S1	To provide remote communication during testbed
HD Webcam	To provide life HD video streaming testbed
GPS Module	To provide ToMRobot location during MANET testbed
Triple Axis Accelerometer Sensor	To provide ToMRobot location during MANET testbed
Ultrasonic Sensor	To allow ToMRobot avoiding any possible obstacle during testbed

Figure 5. ToMRobot Components for MANET Testbed (Actual Implementation)
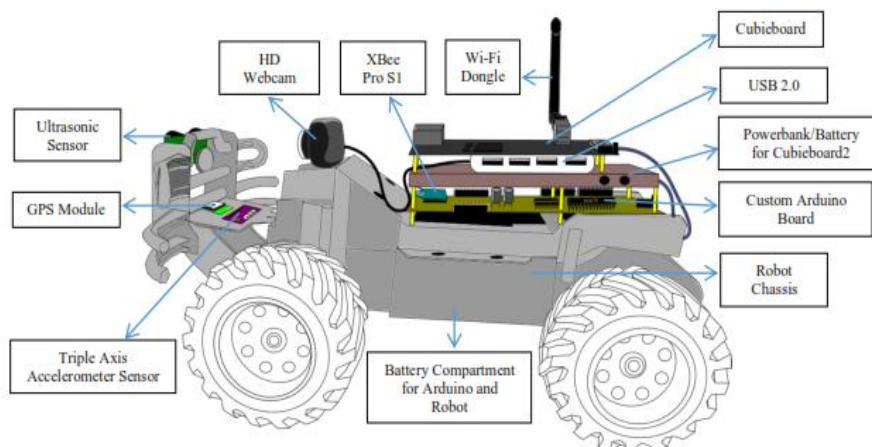
Figure 6. ToMRobot Components for MANET Testbed (Concept Design)

3.3. Software

The last component of ToMRobot is the software, which acts as the brain or control centre of the robot that is based on logic that has been set in advance by the robot builder. The software component also acts in translating the input received from the input components and using that information to make decisions before translating it into output components such as the movement of robot's wheels, legs, or arms.

There are three software that have been used in this study; Robotic Operating System (ROS), Rvis and Gazebo. ROS was used as a robot operating and monitoring system. The Rosserial protocol was used to allow the ROS to be able to communicate with the ToMRobot via XBee wireless communication. Concomitantly, by using Rosserial, it negated the need to develop another new ROS driver to control the ToMRobot, which would increase the testbed development. Through a combination of the ROS, Rosserial and Gazebo, the coordinator will give directions to the ToMRobot testbed for executing the testbed. Simultaneously, the

ToMRobot will return the current status of the ToMRobot, mobile devices (Cubieboard2) and testbed data that is captured in real time.

4. Conclusion

The two prong objectives of this paper has been met, that is (i) to be source of reference for other MANET researchers who are considering the choice of the most suitable mobile robots for real mobility in their MANET testbeds. (ii) to be source of reference for MANET researchers to build their own MANET robots that can be used in their future MANET testbed.

The approach used to develop ToMRobot has the advantage of using easily obtainable and affordable robotic components like a remote control car, which serves as the robot chassis, combined with the use of open hardware technology like Cubieboard2 and Arduino as the robot controller. These combined factors is what enables this robot to be conveniently developed by anyone who is interested to use it in their MANET testbeds. The provided guidelines in this article will aid MANET researchers who lack the technical background to build their own robot and ultimately increase the number of MANET researchers who choose testbeds as their evaluation tool.

This article also serves as a preliminary step for the development of future research projects. For future work, the ToMRobot will be used to measure energy efficiency in MANET testbeds. Two types of MANET testbeds will be designed and set up for the experiment; (i) passive mode and (ii) testbed with mobility. The remote car chassis used in this paper will also be changed to a Tamiya tank remote car chassis so that it can climb obstacles with ease and traverse crevasses without the wheels getting stuck.

The extension of this article can be referred to our paper entitled "*A Technical Review of MANET Testbed Using Mobile Robot Technology*" [54] and "*A Critical Review of MANET Testbed Using Mobile Robot Technology*" [55].

5. Acknowledgements

References

[1]   Rensfelt O Hermans F Gunningberg P Larzon L.-Å. and Björnemo E 2011 *The Computer Journal*, **54** (12) pp 1973–1986

[2]   Yoon H Kim J Ott M, and Rakotoarivelo T 2009 *Proc. of the 4th ACM International Workshop on Experimental Evaluation and Characterization, WINTECH '09* (New York, NY, USA: ACM) pp 51–58

[3]   Raychaudhuri D Seskar I M Ott M Ganu S Ramachandran K Kremo H, Siracusa R Liu H, and Singh M 2005 *Wireless Communications and Networking Conf., 2005 IEEE*, Vol. 3 pp 1664–1669.

[4]   Hahn D Lee G Kim Y Walker B Beecher M and Mundur P 2010 *Proc. of the 5th ACM Workshop on Challenged Networks, CHANTS '10,* (New York, NY, USA: ACM) pp. 79–82

[5]   Kim Y Taylor K Dunbar C Walker B and Mundur P 2011 *Proc. of the 3rd ACM International Workshop on MobiArch, Hot Planet '11,* (New York, NY, USA: ACM) pp 23–28

[6]   Nordstrom E Gunningberg P and Lundgren H 2005 *1ˢᵗ International Conf. on Testbeds and Research Infrastructures for the Development of Networks and Communities*, 2005. Tridentcom'05 pp100–109

[7]   Wang X Borries K Anderson E and Steenkiste P 2011 *2011 IEEE Vehicular Technology Conf. (VTC Fall)* pp 1–5.

[8]   Hortelano J Cano J-C Calafate C T and Manzoni P 2009 *EURASIP J. Wireless Communication Networking* pp 47:1–47:9.

[9]   Zhang Y and Li W 2001 *Proc. of the 3rd ACM International Symposium on Mobile Ad Hoc Networking & Computing (MobiHoc'02)*, (new York, NY, USA: ACM) pp 104–111

[10]   Guruprasad S Ricci R and Lepreau J 2005 1st *International Conf. on Testbeds and Research Infrastructures for the Development of Networks and Communities, 2005. Tridentcom'05* pp 204–212

[11]   Krop T Bredel M Hollick M and Steinmetz R 2007 *Proc. of the 2nd ACM International Workshop on Wireless Network Testbeds, Experimental Evaluation and Characterization, WinTECH '07,* (New York, NY, USA: ACM) pp 27–34

[12]   P. Mahadevan, A. Rodriguez, D. Becker, and A. Vahdat, *2005 Workshop on Wireless Traffic Measurements and Modeling, WiTMeMo '05,* USENIX Association, Berkeley, CA, USA, 2005, pp 7–12.

[13]   Friginal J Andrés D de Ruiz J-C and Martínez M 2015 *Computer Networks* 82 pp 114–134.

[14]   Coulson G B Porter B Chatzigiannakis I Koninis C Fischer S Pfisterer D Bimschas D Braun T Hurni P Anwander M Wagenknecht G Fekete S P Kröller A and Baumgartner T 2011 *Commun. ACM* **55**(1) pp 82–90

[15]   Kulla E Ikeda M Barolli L Xhafa F and Iwashige J, 2012 *A Survey on MANET Testbeds and Mobility Models* (eds) Park J J J H Chao H-C Obaidat M S Kim J Computer Science and Convergence, LNEE (Heidelberg: Springer Berlin) **Vol 114** pp 651–657

[16]   Ramanathan R Redi J Santivanez C Wiggins D and Polit S, 2005 *IEEE Journal on Selected Areas in Communications* **23**(3) pp 496–506

[17]   Galati A Bourchas T Siby S Frey S Olivares M Mangold S, 2014 *2014 IEEE Global Humanitarian Technology Conference (GHTC)* pp 699–705

[18]   Zarafshan-Araki M and Chin K-W 2010 *Computer Communications* **33**(15) pp 1850–1863

[19]   Kazdaridis G and Stavropoulos D Maglogiannis V Korakis T Lalis S Tassiulas L 2014 *2014 IEEE 15th International Conf. on Mobile Data Management (MDM),* Vol. 1 pp 89–98

[20]   Kulla E Oda T Ikeda M Barolli L Biberaj A and Shurdi O, 2014 *Int. J. Wire. Mob. Comput.* **7**(4) pp 318–326

[21]   M. J. F. Alenazi, E. K. Çetinkaya, J. P. Rohrer, *International Telemetering Conf. Proc*

[22]   De, L P Maestre J Camacho E and Alonso I 2011 *International Journal of Ad Hoc and Ubiquitous Computing* **7**(3) pp 192–201.

[23]   De P Raniwala A Krishnan R Tatavarthi K Modi J Syed N A Sharma S and Chiueh T-C 2006 *Proc.of the 4th International Conf. on Mobile Systems, Applications and Services, MobiSys'06,* (New York, NY, USA: ACM) pp 124–137.

[24]   Mitchell C Munishwar V Singh S Wang X Gopalan K and Abu-Ghazaleh N 2009 *Communication Systems and Networks and Workshops (COMSNETS 2009)* First International pp 1–10

[25]   Munishwar V Singh S Wang X Mitchell C Gopalan K and Abu-Ghazaleh N *IEEE International Conference on Pervasive Computing and Communications (PerCom 2009)* pp. 1–6.

[26]   Munishwar V Singh S Mitchell C Wang X Gopalan K Abu-Ghazaleh N 2009 *IEEE International Conf. on Pervasive Computing and Communications (PerCom 2009)* pp 1–3.

[27]   Becue P Jooris B Sercu V Bouckaert S Moerman I and Demeester P *Remote Control of Robots for Setting Up Mobility Scenarios during Wireless Experiments in the IBBT w-iLab.t,* (eds) Ko- rakis T Zink M Ott M LNICST (Heidelberg: Springer Berlin) **44** pp 425–426

[28]   Moerman L Korakis T Niavis, H Stavropoulos D Igoumenos I Becue P Sercu V Jooris B Neuhaus S Lyberopoulos G Theodoropoulou E and Filis K Toolkit for wireless mobility testbeds, Deliverable Report Deliverable D3.5, OpenLab (Oct. 2014)

[29]   Abdelhadi A Rechia F Narayanan A Teixeira T Lent R Benhaddou D Lee H and Clancy T C, Position Estimation of Robotic Mobile Nodes in Wireless Testbed using GENI, arXiv preprint arXiv: 1511.08936.

[30] Reich J Misra V and Rubenstein D 2 0 0 8 *A CM SIGMOBILE Mobile Computing and Communications Review* **12**(1) pp 68–70

[31] Reich J Misra V Rubenstein D and Zussman G 2012 *IEEE Journal on Selected Areas in Communications* **30**(5) pp 935–950

[32] Bromage S Engstrom C Koshimoto J Bromage M, Dabideen S and Hu M Menchaca-Mendez R Nguyen D Nunes B Petkov V Sampath D Taylor H Veyseh M Garcia-Luna-Aceves J JObraczka K Sadjadpour H Smith B 2009 *ACM SIGMOBILE Mobile Computing and Communications Review* **13** (1) pp 65–68

[33] Janansefat S Senturk I Akkaya and K Gloff M 2012 *37th Annual IEEE Conf. on Local Computer Networks (LCN)*

[34] Rensfelt O Hermans F Larzon L-Å and Gunningberg P, 2 0 1 0 *Proc. of the 5th ACM International Workshop on Wireless Network Testbeds, Experimental Evaluation and Characterization, WiNTECH'10,* (New York, NY, USA: ACM) pp63–70

[35] Hermans F Rensfelt O Gunningberg P, Larzon L-Å and Ngai E C, *TRIDENTCOM, 2010, pp*

[36] Vingelmann P Pedersen M Heide J Zhang Q and Fitzek F 2012 *IEEE International Conf. on Communications (ICC 2102)* pp 291–296

[37] Vingelmann V Heide J Pedersen M V Zhang Q and Fitzek F H P, 2014 *Computer Networks* 74(Part B) pp 34–47

[38] Johnson D Stack T Fish R Flickinger D Ricci R and Lepreau J 2006 *The 25th Annual Joint Conf. of the IEEE Computer and Communications Societies.* IEEE Computer Society

[39] Johnson D Stack T Fish R Flickinger D Stoller L Ricci R and Lepreau J 2006 *25th IEEE International Conf. on Computer Communications (INFOCOM'*06) pp 1–12

[40] Arora A, E Ertin E Ramnath R Nesterenko M and Leal W 2006 *IEEE Internet Computing* **10**(2) pp 35–47.

[41] Ertin E Arora A Ramnath R Nesterenko M, Naik V Bapat S Kulathumani V Sridharan M Zhang H and Cao H 2006 *The 5th International Conf. on Information Processing in Sensor Networks (IPSN 2006)* pp 399–406

[42] Forster A Forster A Leidi T Garg K Puccinelli D Ducatelle F Giordano S and Gambardella L M 2010 MOTEL: Towards F l e x i b l e Mobile Wireless Sensor Network Testbeds, 2010.

[43] Förster A Förster A Garg K Puccinelli D Giordano S and Gambardella L M 2013 *Wireless Integration of Sensor networks in Hybrid architectures* 13

[44] Foerster A Foerster A Garg K Giordano S and Gambardella L M *Adhoc & Sensor Wireless Networks* **24**(3)

[45] Jiménez-González A Martínez-de Dios J R and A. Ollero A, 2010 *IEEE/RSJ International Conf. on Intelligent Robots and Systems (IROS 2010)* pp 3327–3332

[46] Jimenez-Gonzalez A Martinez-De Dios J R and Ollero A 2 0 1 1 *Sensors* **11**(12) pp 11516–11543

[47] Jiménez-González A Martinez-de Dios J R and Ollero A 2013 *Robotics and Autonomous Systems* **61**(12) pp 1487–1501

[48] Dios J R M.-d Jimenez-Gonzalez A Bernabe A. d. S. and Ollero A 2014, A Remote Integrated Testbed for Cooperating Objects, S p r i n g e r B r i e f s in Electrical and Computer Engineering, S p r i n g e r International Publishing, pp 23–39.

[49] Killijian M-O Roy M a n d Severac G 2010 *IEEE 6th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob 2010)* pp 442–449

[50] Killijian M-O Roy M and Severac G 2 0 1 2 *The ARUM Experimentation Platform: An Open Tool to Evaluate Mobile Systems Applications (eds)* RÃŒckert U Joaquin S Felix W (Heidelberg: Springer Berlin) pp. 221–234.

[51] Dahlberg T A Nasipuri A and Taylor C 2005 *Proc. of the 2005 ACM SIGCOMM Workshop on Experimental Approaches to Wireless Network Design and Analysis (E-WIND '05)* (New York, NY, USA: ACM) pp 76–81

[52] Niavis H Kazdaridis G Korakis T and Tassiulas L Enabling Sensing and Mobility on Wireless Testbeds 2012 (eds) Korakis T Zink M Ott M LNICST (Heidelberg: Springer Berlin) **44** pp 421–424

[53] Quilez R Zeeman A Mitton N and Vandaele J, Docking autonomous robots in passive docks with Infrared sensors and QR codes, 2015.

[54] Farkhana Muchtar, Abdul Hanan Abdullah, Muhammad Shafie Abd Latiff, Suhaidi Hassan, Mohd Helmy Abd Wahab, and Gaddafi Abdul-Salaam 2017 A Technical Review of MANET Testbed Using Mobile Robot Technology *J. Phys.: Conf. Ser*

[55] Farkhana Muchtar, Abdul Hanan Abdullah, Marina Md Arshad, Mohd Helmy Abd Wahab, Siti Nor Zawani Ahmmad and Gaddafi Abdul-Salaam 2017 A Critical Review of MANET Testbed Using Mobile Robot Technology *J. Phys.: Conf. Ser*