Challenging Wireless Networks, an Underground Experience

David Palma, Joao Goncalves, and Marilia Curado

Department of Informatics Engineering
Centre for Informatics and Systems University of Coimbra (CISUC)
{palma,marilia}@dei.uc.pt, jccg@student.dei.uc.pt

Abstract. Quite often Wireless Ad-hoc networks are taken for granted as a networking solution in the most challenging environments. Motivated by these networks' self-X properties and the infrastructure-less paradigm, many authors rely on Ad-hoc networks to support a number of applications in remote areas or even in disaster scenarios such as mine collapses, earthquakes, tunnel accidents. However, most of these works are only simulation oriented, disregarding how challenging wireless networks can be in such scenarios. By conducting a set of performance measurements with off-the-shelf netbooks in an underground environment it is possible to see that typical wireless simulation assumptions do not verify, and that covering an area with multi-hop connectivity is not straightforward. These results motivate a tighter interaction between real experiments and future simulation based works in challenging environments which need to be more accurate.

1 Introduction

The dissemination of new portable devices with enhanced communication characteristics has revolutionized the world in many aspects. Not only on the social side, where people are connected by their cell phones, personal digital assistants (PDAs) or laptops, but also on an economical and professional perspective, where these devices have introduced new ways of dealing with different situations. In fact, it is expected that in a near future, users will own several wireless enabled gadgets [9], demanding infrastructures or other connectivity alternatives such as Mobile Ad-hoc NETworks (MANETs).

In order to support the creation of Ad-hoc Networks, several routing protocols have been proposed, using a myriad of approaches to tackle the different aspects of these networks [3]. The existing routing protocols can be grouped into three different main classes: Proactive, Reactive and Hybrid, where the main difference between these classes relies on how routing information is exchanged. An additional class of Position Based routing protocols can also be considered, as no explicit exchange of routing messages is required. However, these protocols may not always be suitable in scenarios where position information is not available or accurate.

J. Del Ser et al. (Eds.): MOBILIGHT 2011, LNICST 81, pp. 312–321, 2012.

Despite all the proposed routing approaches for Multi-hop Networks, since the definition of the concept of Ad-hoc Wireless Networking in the early 70's for battlefields, the actual usage of these networks is very modest even with all the possible advantages. Currently, no particular applications seem to stand out as standard applications [14]. Following the same background on which Ad-hoc Networks were first used, rescue operations have been considered as one of the most suitable scenarios for the implementation of these infrastructure-less wireless networks, supporting monitoring and coordination applications typically required by rescue teams in disaster scenarios [15].

The requirements of wireless networks for rescue operations are very complex and different, depending on the specifics of each rescue operation being considered [22] [20]. In particular, these networks and their behaviour are closely related with the surrounding environment, where the physical scenario characteristics and obstacles are considered a major challenge [4].

Simulations provide an important contribution for the research community but usually depend on a number of assumptions which cannot be verified in the real world [17]. Therefore, the aim of this paper is to provide a new perspective on the behaviour of wireless networks within an underground scenario, presenting real measurements obtained using off-the-shelf "Asus EEE" netbooks, not requiring any additional hardware, representing a configuration likely to be used by any element of a rescuing team. A thorough evaluation of the wireless link performance using this equipment is presented, and an illustrative small scale Ad-hoc network using the Optimized Link State Routing Protocol (OLSR) [10] protocol is also analysed.

In section 2 works related with the creation of wireless networks in challenging environments are presented, followed in section 3 by the definition of challenging wireless networks, and by a real experimental scenario with those characteristics. The registered experiences and obtained results are presented in section 4, leading to the final thoughts on Wireless Communication in Challenged Environments, in section 5.

2 Related Work

Considering the usage of Ad-hoc Networks for dynamic infrastructure-less networks, a number of routing schemes has already been proposed. For topology-based routing protocols, which do not require any additional mechanism for node's position awareness such as the global positioning system (GPS) or other positioning schemes, several proposals have been developed for both proactive [10] [11] and reactive [19] [6] routing protocols.

These protocols aim at providing a reliable self-X networking "infrastructure", allowing the deployment of Ad-hoc networks anywhere at anytime in order to support all the necessary computer communications. Such a flexible and dynamic perspective on wireless networks motivated several authors to investigate on how search/rescue and monitoring applications can be applied to challenging scenarios such as earthquakes, mines, tunnels and even underwater. However, most of

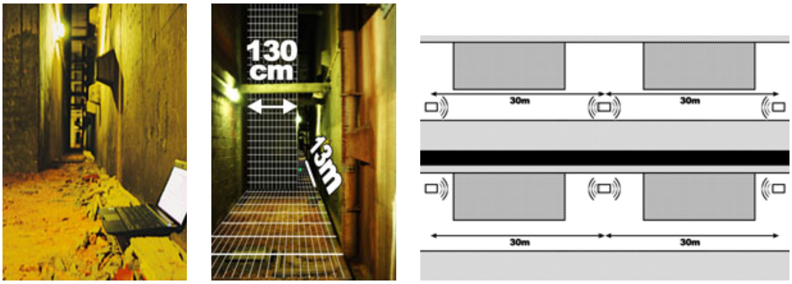

Fig. 1. Underground Gallery Settings

the existing works are based on simulation studies [5] [7], which are important for the development of new revolutionary schemes, specially when dealing with larger networks - as it might be extremely difficult, if not impossible in certain situations, to perform real experiments - but which depend on a considerable number of assumptions, failing many times to provide an accurate perspective on systems' behaviour in particular when these conditions are not predictable in extreme environments.

Other existing works, for instance in underground communication, consist on the proposal of complex architectures which are not representative of the Ad-hoc communication paradigm, creating a wireless infrastructure and relying on hardware specific equipment such as high debit antennas [18] [24]. Through the manipulation of experimental environments, by using obstacles and other means, some authors have presented results in scenarios with similar characteristics of those expected to be found in earthquake or urban search & rescue situations, attempting to accurately portray the possible situations found in a real scenario [8] [21].

The understanding of wireless link quality and how it is influenced represents an important subject of research [12]. This is relevant not only for the existing and upcoming routing protocols (see section 14 of [10]), but also to allow the correct modelling of their behaviour, improving the existing network simulators and their results [13].

3 Challenging Wireless Networks

The creation of wireless networks in challenging scenarios is frequently seen as the most efficient way of allowing networking in such locations. These scenarios are considered challenging due to many different factors, which can be related with the permanent nature of the physical scenario conditions and its vicinities, such as underground chambers, underwater spaces or even remote areas with extremely difficult access. However, the choice of wireless networking in these scenarios is mainly due to destructive natural phenomena such as earthquakes, hurricanes, floods, or even due to human related accidents.

Typically, human built structures, such as mines and tunnels have their own communication infrastructures built "a priori", using many times the most easily maintainable and affordable solution. It is when these solutions fail, due to some of the aforementioned situations, that Ad-hoc wireless approaches are more seriously taken into account in order to support search and rescue operations that require all the possible help in the task of looking for and saving trapped victims.

3.1 Problem Statement

As wireless networks in challenging environments are mainly targeted at providing a good coverage of the possibly affected areas, the presented evaluation is focused on the performance of a wireless link at different distances, with static nodes, using single and multi hop connections. This multi-hop study is particularly important when existing obstacles significantly jam the wireless link between two nodes, requiring at least an additional node in a crossing point, connecting the whole network.

The main focus of this work is to evaluate the wireless link performance, bandwidth and losses. These parameters were measured using several payloads and different physical wireless characteristics. Moreover, the OLSRd protocol [23] was used to evaluate multi-hop performance, even though static routes had to be used in certain situations, as presented in section 3.1. Despite the existence of other routing alternatives exist such as the Babel and the B.A.T.M.A.N protocols [16], the OLSRd protocol was chosen for its popularity.

Scenario Description. With the purpose of providing accurate measurements on a representative scenario of a challenging environment, a set of performance evaluation tests was taken with off-the-shelf netbooks positioned within a subterranean gallery. This gallery was constructed to monitor the underground movements of a main wall supporting the building on against a mountain. Moreover, this gallery also constantly drains all the existing groundwater, creating a very humid scenario, with barely any interferences from other wireless equipments.

The gallery where the main tests were performed is presented in figure 1, and consists on a corridor about $2.3m$ wide, interrupted by 1.3 by 13 meter blocks where elevators and stairs were built. These obstacles clearly interrupt the propagation of the wireless signal, being representative of possible debris in disaster scenarios and requiring extra wireless coverage.

In order to assess the quality of the wireless ad-hoc network created in this scenario, several measurements with different characteristics were taken. First, by always having a clear line of sight, a single hop link of 20, 30, 40 and 60 meters was evaluated, varying the link bit rate between $1Mb/s$, $11Mb/s$, $54Mb/s$ and $auto$. The chosen bit rates respectively represent the lowest bit rate possible, the $802.11b$ standard, the $802.11g$ and an automatically adapted link rate. This assessment was performed by using the Iperf [2] tool in UDP mode, with 3 different payloads (1, 5 and 10 MByte), in order to determine the overall performance of the link. Secondly, an additional single link measurement was also performed by placing the netbooks such that there would be no line of sight, with each node distanced by $30m$. No other distances were measured with these obstacles as no connectivity was obtained. During this section all the results presented as "30*" represent the values obtained when nodes are placed with no line of sight at a $30m$ distance.

The multi-hop evaluation was performed between three nodes distanced by $30m$ from each other, both with obstacles and with clear line of sight. One important experience gathered from this evaluation is related with the usage of the OLSRd protocol for route establishment. Even though the single-hop measurements indicated that virtually no data packets could be transmitted at a distance of $60m$, such links were considered as reliable by the OLSRd protocol, leading to single-hop communication and subsequent loss of all the packets. However, this would only happen with a clear line of sight, since with obstacles the $60m$ link was not detected and multi-hop was correctly established.

Equipment Specification. One of the most important contributions of this work, besides the performed measurements in a real challenging environment, is that no hardware specific assumptions were taken. All the presented results were obtained with an off-the-shelf equipment, an Asus EEE netbook. The particular model used was the 1001 PX with an Intel Atom 450, 1GB Ram and an Atheros Communication Wireless Card (model AR9285, ath9k driver), running the Linux distribution Ubuntu 10.04 Netbook Edition (kernel 2.6.32). No modifications were performed to the hardware, using the default embedded antennas.

Due to the extensive and repetitive amount of performed measurements the nodes were not running on batteries, even though some preliminary tests showed no difference between working with batteries or being connected to an AC Adapter, as long as the card power save option is turned off. In a real rescue scenario these devices would most likely be running on batteries and the expected consumption of the wireless card (with no power saving scheme) would be of 1090mW [1] when not in idle.

4 Underground Measurements and Analysis

All the presented results represent an average sample obtained from 30 measurements taken sequentially by using a script. This allows an accurate understanding of the wireless link characteristics, such that no variations influence the overall interpretation of the results. Moreover, only UDP measurements were performed in order to avoid dynamic adjustment procedures such as TCP congestion control. These results show a 95% confidence interval, obtained from the central limit theorem.

4.1 Link Quality

The measured link quality is characterized by the signal to noise ratio obtained from the network card driver used by the Linux kernel. This value was also collected 30 times with a 5 second interval between each measurement. In figure 2 it is possible to see that there is not much granularity in the link quality value,

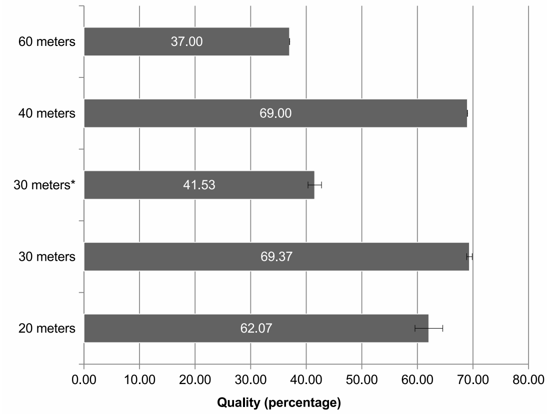

Fig. 2. Average Link Quality Percentage

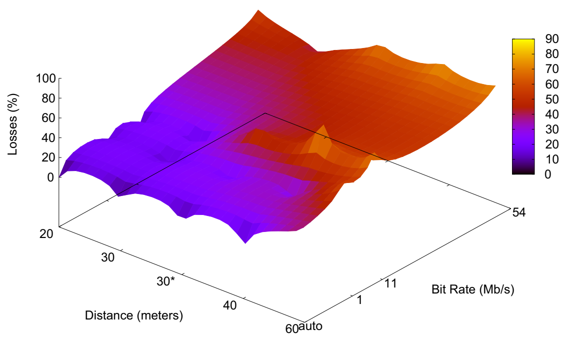

Fig. 3. Average Losses

being hard to see the difference between 30 and 40 meters. However, as shown further in this work, this $10m$ variation in distance has a strong impact in losses, specially for higher data rates. This figure also shows that at 20m the variance is bigger and link quality is worse than for $30m$. Usually the closer the better, but in this scenario, due to the presence of obstacles, the wireless link performance at $20m$ may degrade as a result of being closer to the existing obstacles.

4.2 Losses

The results presented in figure 3 show that the number of losses depends on a combination of the link distance between two wireless nodes and the data bit rate being used. For instance, considering higher distances (e.g. 60m), only lower bit rates such as 1 and $11Mb/s$ are able to send packets with fewer losses, as it would be expected.

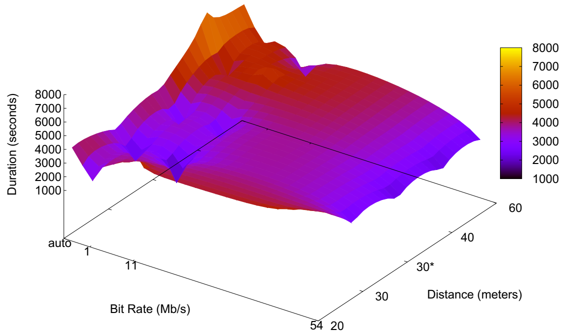

Fig. 4. Average Time Elapsed per Measurement

Focusing on the results obtained for each bit rate, it is clear that the *auto* mode has less losses at any distance. At $1Mb/s$ the obtained results are similar but start to degrade at 60m. For a rate of $11Mb/s$ the number of losses increases at $40m$ while at $54Mb/s$ a high number losses is registered at all distances.

4.3 Elapsed Time

Another aspect that was taken into account while evaluating the perform of wireless Ad-hoc networks was the time required to transmit all the sent data. This parameter depends not only on the amount of data to be transmitted and the used bit rate but also on the wireless medium availability, taking more time to transmit the data when collision avoidance mechanisms are used.

The values presented in figure 4 show the duration, in average, of the total time taken while performing the measurements, averaging the different UDP payloads used. The most interesting result perceived is that the good delivery performance of the *auto* bit rate has a cost since it takes more time to transmit the required data. Moreover, this increase of the total elapsed time is also noticeable even when all the traffic fails to be received. This occurs when the *auto* property is active because the sender keeps trying to adjust the bit rate to send data, even though it is physically impossible.

4.4 Multi-hop Experiments

The obtained quality values for a wireless link are important when considering multi-hop routing such that a routing protocol is able to detect whether a link is reliable or not, allowing it to correctly calculate routing paths. However, from the obtained experience a link's quality does not reflect by any means its reliability. This issue may possibly lead to inaccurate path choices and in fact, this was observed in the performed experiments when using the OLSRd [23] Linux implementation.

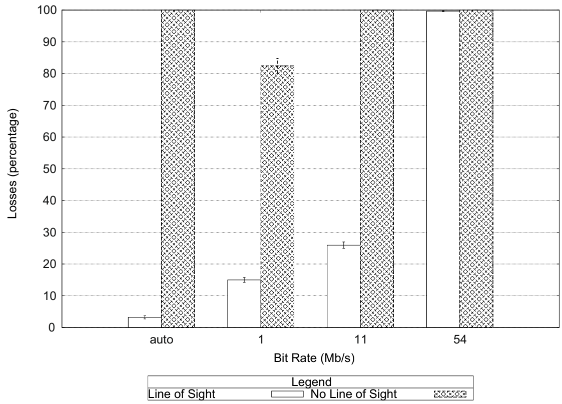

Fig. 5. Average Multi-hop Losses

In figure 5 the multi-hop losses registered between three hops are presented. These nodes, as depicted in figure 1(c) were deployed with and without line-of-sight connectivity. Due to poor link quality assessment, in the scenario with line of sight static routes were used as OLSRd tried to establish single link connection between the end nodes, thus losing all the sent data.

The obtained results show that for lower bit rates, and with line of sight, the amount of losses using multi-hop oscillates from 4 to less than 30%. However, without line of sight the amount of registered losses is greater than expected when comparing with the single-hop case for the same distance, which had a better performance. This increase of losses is explained by incorrect single-hop paths established by the OLSRd protocol when multi-hop had to be used according to the single-hop experiences.

The OLSR protocol specification considers link quality as a “link admission” mechanism such that a node that “hears” a link does not immediately consider it as part of the routing topology. This quality may be measured by analysing signal to noise ratio or by keeping packet reception and loss information, for instance by checking message sequence numbers. However, the obtained results reveal that this scheme is still prone to errors, resulting in incorrect routing paths and consequent losses.

5 Conclusion

Wireless Networking in challenging environments has been long considered as one of the most promising solutions for connecting teams of search and rescue operations where no communication infrastructures may exist. In particular, Ad-hoc networks, for their self-X characteristics, have been analysed by many authors to support different applications in such scenarios. However, the majority of the existing studies are simulation based or are not taken in real challenging scenarios with realistic equipments. In this work a set of thorough wireless performance tests are taken in an underground gallery, using off-the-shelf wireless equipments, which can truly represent a scenario for a challenging rescue operation.

By performing several measurements in a humid underground gallery using Iperf in UDP mode, losses and link quality results for both single and multi-hop cases were gathered. Moreover, different distances separating the nodes with and without line of sight and different bit rates were also considered. The obtained results allow future research works in this area to provide more accurate conclusions on how wireless networks behave in challenging environments and what sort of applications are suitable in these scenarios.

Taking into account the number of registered losses versus the distances and available bit rates, it is clear that providing wireless network coverage in a challenging environment is still an issue. In particular, this issue results from poor multi-hop routing path establishment when using a well known Ad-hoc routing protocol, OLSRd. This protocol failed to successfully manage the existing routes, establishing incorrect single-hop links due to the poor relation between the measured link quality (considering the signal to noise ratio) and actual link performance.

The main registered problems are related with network partitioning, limited bit rates and high delay, suggesting that delay tolerant solutions as well as link quality metrics considerations have to be taken into account for efficient multi-hop routing in real challenging environments.

Acknowledgement. This work was supported by the Portuguese National Foundation for Science and Technology (FCT) through a PhD Scholarship (SFRH / BD / 43790 / 2008) and by the National Project MORFEU (PTDC / EEA-CRO / 108348 / 2008).

References

1. The atheros ath9k power consumption, `http://wireless.kernel.org/en/users/Drivers/ath9k/power-consumption/`
2. NLANR/DAST: Iperf - the TCP/UDP bandwidth measurement tool, `http://iperf.sourceforge.net/` (accessed 2010)
3. Abolhasan, M., Wysocki, T., Dutkiewicz, E.: A review of routing protocols for mobile ad hoc networks. Ad Hoc Networks 2(1), 1–22 (2004)
4. Ahmed, S., Karmakar, G.C., Kamruzzaman, J.: An environment-aware mobility model for wireless ad hoc network. Computer Networks 54(9), 1470–1489 (2010)
5. Cayirci, E., Tezcan, H., Dogan, Y., Coskun, V.: Wireless sensor networks for underwater survelliance systems. Ad Hoc Networks 4(4), 431–446 (2006)
6. Chakeres, I., Perkins, C.: Dynamic manet on-demand (dymo) routing. Work in progress, internet-draft, Internet Engineering Task Force (July 2010), `http://www.ietf.org/internet-drafts/draft-ietf-manet-dymo-17.txt`
7. Chen, G.Z., Shen, C.F., Zhou, L.J.: Design and performance analysis of wireless sensor network location node system for underground mine. Mining Science and Technology (China) 19(6), 813–818 (2009)
8. Chen, Z., Chen, L., Liu, Y., Piao, Y.: Application research of wireless mesh network on earthquake. In: International Conference on Industrial and Information Systems, IIS 2009, 24-25, pp. 19–22 (2009)

9. Cimmino, A., Donadio, P.: Overall requirements for global information multimedia communication village 10th strategic workshop. Wireless Personal Communications 49(3), 311–319 (2009), http://dx.doi.org/10.1007/s11277-009-9686-3
10. Clausen, T., Jacquet, P.: Optimized link state routing protocol (olsr). RFC 3626, Internet Engineering Task Force (October 2003), http://www.ietf.org/rfc/rfc3626.txt
11. Eriksson, J., Faloutsos, M., Krishnamurthy, S.V.: Dart: Dynamic address routing for scalable ad hoc and mesh networks. IEEE/ACM Transactions on Networking 15, 119–132 (2007)
12. Gaertner, G., Cahill, V.: Understanding link quality in 802.11 mobile ad hoc networks. IEEE Internet Computing 8(1), 55–60 (2004)
13. Garg, V.K.: Radio propagation and propagation path-loss models. In: Wireless Communications & Networking, pp. 47–84. Morgan Kaufmann, Burlington (2007)
14. Gerla, M.: From battlefields to urban grids: New research challenges in ad hoc wireless networks. Pervasive and Mobile Computing 1(1), 77–93 (2005)
15. Khoukhi, L., Cherkaoui, S., Gaiti, D.: Managing rescue and relief operations using wireless mobile ad hoc technology, the best way? In: IEEE 34th Conference on Local Computer Networks, LCN 2009, 20-23, pp. 708–713 (2009)
16. Murray, D., Dixon, M., Koziniec, T.: An experimental comparison of routing protocols in multi hop ad hoc networks. In: 2010 Australasian Telecommunication Networks and Applications Conference, ATNAC, 31 (2010)
17. Newport, C., Kotz, D., Yougu, Y., Gray, R.S., Jason, L., Elliott, C.: Experimental evaluation of wireless simulation assumptions. Simulation 83(9), 643–661 (2007)
18. Nielsen, Y., Koseoglu, O.: Wireless networking in tunnelling projects. Tunnelling and Underground Space Technology 22(3), 252–261 (2007), http://www.ietf.org/rfc/rfc3561.txt
19. Perkins, C.E., Belding-Royer, E.M., Das, S.R.: Ad hoc on-demand distance vector (aodv) routing. RFC Experimental 3561, Internet Engineering Task Force (July 2003), http://www.ietf.org/rfc/rfc3561.txt
20. Plagemann, T., Munthe-Kaas, E., Skjelsvik, K.S., Puzar, M., Goebel, V., Johansen, U., Gorman, J., Marin, S.P.: A data sharing facility for mobile ad-hoc emergency and rescue applications. In: ICDCSW 2007: Proceedings of the 27th International Conference on Distributed Computing Systems Workshops, p. 85. IEEE Computer Society, Washington, DC (2007)
21. Ribeiro, C., Ferworn, A., Tran, J.: An assessment of a wireless mesh network performance for urban search and rescue task. In: 2009 IEEE Toronto International Conference Science and Technology for Humanity (TIC-STH), 26-27, pp. 369–374 (2009)
22. Sha, K., Shi, W., Watkins, O.: Using wireless sensor networks for fire rescue applications: Requirements and challenges. In: 2006 IEEE International Conference on Electro/information Technology, 7-10, pp. 239–244 (2006)
23. Tnnesen, A., Lopatic, T., Gredler, H., Petrovitsch, B., Kaplan, A., Tcke, S.O., et al.: Olsrd - an ad-hoc wireless mesh routing daemon (July 2010), http://www.olsr.org
24. Wenfeng, L., Jie, G., Peng, B.: Mine multimedia emergency communication system. In: International Conference on Wireless Communications, Networking and Mobile Computing, WiCom 2007, 21-25, pp. 2865–2868 (2007)