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Self-Healing in Wireless Sensor Networks

Andrew Durant

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Supervisor: James Harbin

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Abstract

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In order to consider self-healing in real-world applications of wireless sensor networks an understanding of the possible applications is required. A survey of approaches to self-healing is then presented along with metrics that can be used to evaluate and compare them. This is followed with a review of evaluation techniques and real-world factors for wireless sensor networks.

2.1 WSN applications

The possible applications for wireless sensor networks are diverse and far reaching. The small self-powered devices that can gather data from a wide area, to detect events and communicate information back to a base station either processed or for processing lend themselves to a large number of applications. Each of these applications utilise the WSN in different ways and thereby bring new challenges to the developer of the systems. Due to this the design of the network is highly dependent on the application domain. Just some of the fields WSNs have been used in are environmental monitoring, warfare, agriculture, surveillance, medical care, education and micro-surgery.

Habitat monitoring using WSNs has been taking place on an island of ducks where ordinary monitoring techniques cause disturbance to the animals with problems such as increasing mortality and eventual abandonment of the habitat. The use of WSNs that can be deployed prior to seasonal habitation enables constant monitoring over the time without the need to disturb the inhabitants. Mainwaring et al. [1] detail the requirements of the network and how it has been developed. Longevity of the devices, remote management, and inconspicuous operation are required to ensure the WSN is reliable and the data is able to be collected. The locations used for WSNs are often extreme, particularly for habitat monitoring. Similar requirements to the above are generated by Biagioni and Bridges [2] for monitoring endangered plants. Most importantly however for collecting scientific data is ensuring the system is reliable

and the user can have confidence in the data.

A very different approach was taken by Juang et al. [3] in developing ZebraNet. Rather than statically positioned nodes, the devices are attached to the herd of zebra being monitored with collars. The nature of this system is entirely mobile, without even a fixed base station to report to. Because of this the nodes pass data between them when within range forming a distributed collection and storage network. The mobile base station can then be deployed occasionally to collect the dataset only needing to meet a few devices to obtain all of the data gathered by the network. This network is inherently ad-hoc where nodes may or may not come into contact with one another frequently, and there is no fixed or permanent base station to report to. Again longevity is an important requirement as deploying or re-deploying the sensors requires capture of the animals, so the systems must run for at least a year with no intervention.

Environmental monitoring on volcanoes has been investigated by Werner-Allen et al. [4] where the use of WSNs enables data collection over a wider area for a longer amount of time compared to using traditional equipment. WSN nodes can be deployed easily and left unattended to monitor the volcano area over a period of several weeks or months. Whereas traditional equipment is bulky and heavy, and therefore difficult to deploy limiting the area of research. The WSN transmitting the collected data back to the base station also removes the need to frequently return to the sensor devices to retrieve data. This is a clear example of using the advantages of wireless sensor networks. However a number of potential issues are raised. The nodes are deployed at the limits of their range to the nearest neighbour, this allows as large an area as possible to be covered, however if a single node fails all other nodes that were dependent upon it will be unreachable. In the scale of this network, where the maximum hop length from the base station is 6 this may seem insignificant, however that is 37.5% of the network nodes.

2.2 Approaches to self-healing in WSNs

2.2.1 Centralised

2.2.2 Distributed

There have been many algorithms developed for distributed control and self-healing for WSNs as a large amount to academic research has gone

into systems such as environmental monitoring. A basis for many of these are DARA [5] and PADRA [6] which both aim to restore connectivity to a local area after a node has failed, whilst minimising the total distance travelled, and without external supervision or involvement.

RIM [7] improves upon DARA and PADRA which each need 2-hop knowledge of the network to only requiring 1-hop knowledge on each node. This significantly reduces the network overhead for maintaining the required knowledge of the network topology, however the simplicity means that the distance travelled by the nodes is greater in larger networks for RIM than for DARA or PADRA. Calculating and transmitting a lot of detailed information is often considered too much overhead for low-power, low-complexity systems, particularly if the network can change often or easily. Depending on the application for the WSN the communication overhead to maintain the topology data could be justified over the generally more efficient algorithm.

Another flaw in RIM is that it assumes and requires only one node failure at a time. Whilst this may be the case, failures in WSNs are most commonly battery depletion, which is likely to occur at similar times across the network, or random failure due to environmental conditions, which could happen at any time to one or multiple nodes.

SFRA [8] is designed specifically to deal with multiple simultaneous failures to combat the multiple failure problem in RIM. Network trees are built from the root node, with local cluster-head nodes, this introduces a fair amount of network overhead compared with RIM. The number of updates needed to send is reduced by waiting for all child node messages before propagating back up the tree.

- Only localised algorithms are properly scalable - mobile nodes / redundant distribution - most algorithms require knowledge of location / GPS - biological-inspired approaches

2.3 Metrics for evaluating self-healing WSNs

2.4 Review of evaluation techniques for WSNs

- Weibull reliability function - useful for simulating node failures?

2.5 Conclusions

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Wireless sensor networks are used in a wide range of applications, and in recent times this is only expanding. Due to their nature of being small, low-power devices, and the common network connectivity being multi-hop routing, network drop-outs and partitioning of devices is a common problem that has been tackled in a variety of ways. There are two main approaches to network and device management for combating and fixing these issues, the distributed approach and the centralised approach.

According to Tong et al. [9] self-healing by means of mobile nodes still remains a greatly unstudied area.

The effectiveness of these two approaches is debated, however the application for a particular WSN determines the effectiveness of a particular algorithm or management paradigm. Certain use cases, for example in industrial equipment monitoring, power usage is less likely to be an important contributing factor but speed of detection and recovery might be more pressing. In an environmental monitoring situation network nodes are more likely to be physically difficult to get to once deployed, and longevity of battery power is highly important.

With these considerations, performance metrics for particular algorithms may not give a fair comparison, as algorithms optimised for low power consumption have a very different purpose to those optimised for rapid recovery. However the approaches and algorithms for communication in WSNs are still very different from traditional networking models because it is common for the network topology and availability to change often and quickly, the storage and network capacity is much lower, and wireless channels are prone to interference and drop-outs.

Bibliography

[1] A. Mainwaring, D. Culler, J. Polastre, R. Szewczyk, and J. Anderson, "Wireless Sensor Networks for Habitat Monitoring," *Proceedings of the 1st {ACM} International Workshop on Wireless Sensor Networks and Applications*, pp. 88–97, 2002. [Online]. Available: http://doi.acm.org/10.1145/570738.570751

[2] E. S. Biagioni and K. Bridges, "The Application of Remote Sensor Technology To Assist the Recovery of Rare and Endangered Species," *International Journal of High Performance Computing Applications*, vol. 16, no. 3, pp. 315–324, 2002.

[3] P. Juang, H. Oki, Y. Wang, M. Martonosi, L. S. Peh, and D. Rubenstein, "Energy-efficient computing for wildlife tracking," in *Proceedings of the 10th international conference on architectural support for programming languages and operating systems (ASPLOS-X) - ASPLOS '02*. New York, New York, USA: ACM Press, 2002, pp. 96–107. [Online]. Available: http://portal.acm.org/citation.cfm?doid=605397.605408

[4] G. Werner-Allen, K. Lorincz, M. Welsh, O. Marcillo, J. Johnson, M. Ruiz, and J. Lees, "Deploying a wireless sensor network on an active volcano," *IEEE Internet Computing*, vol. 10, no. April, pp. 18–25, 2006.

[5] A. A. Abbasi, K. Akkaya, and M. F. Younis, "A Distributed Connectivity Restoration Algorithm in Wireless Sensor and Actor Networks," *32nd IEEE Conference on Local Computer Networks (LCN 2007)*, pp. 496–503, 2007. [Online]. Available: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4367880

[6] K. Akkaya, A. Thimmapuram, F. Senel, and S. Uludag, "Distributed Recovery of Actor Failures in Wireless Sensor and Actor Networks," *2008 IEEE Wireless Communications and Networking Conference*, pp. 2480–2485, 2008. [Online]. Available: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4489467

[7] M. F. Younis and S. Lee, "A localized algorithm for restoring internode connectivity in networks of moveable sensors," *Computers, IEEE Transactions*, vol. 59, no. 12, pp. 1669–1682, 2010. [Online]. Available: http://ieeexplore.ieee.org/xpls/abs{_}all.jsp?arnumber=5551121

[8] A. Alfadhly, U. Baroudi, and M. F. Younis, "An effective approach for tolerating simultaneous failures in wireless sensor and actor networks," *Proceedings of the first ACM international workshop on Mission-oriented wireless sensor networking*, pp. 21–26, 2012.

[9] B. Tong, Z. Li, G. Wang, and W. Zhang, "On-Demand Node Reclamation and Replacement for Guaranteed Area Coverage in Long-Lived Sensor Networks," *Quality of Service in Heterogeneous Networks*, vol. 22, pp. 148–166, 2009.